# Institute of Ocean Sciences



## 1985 ANNUAL REVIEW OF ACTIVITIES

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# Institute of Ocean Sciences

*Institute of Ocean Sciences, Patricia Bay*

# 1985

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## Institute of Ocean Sciences

**PATRICIA BAY, SIDNEY, B.C.**

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# Contents


| | |
|---|---|
| DEPARTMENT OF FISHERIES AND OCEANS | 7 |
| Director-General's Foreword | 9 |
| Hydrography | 11 |
| Field Hydrography | 13 |
| Chart Production and Distribution | 15 |
| Tidal and Current Surveys | 18 |
| Engineering Services | 20 |
| Oceanography | 25 |
| Ocean Physics | 27 |
| Fjords and Channels | 27 |
| Straits | 27 |
| Continental Shelf | 28 |
| Deep Sea | 30 |
| Forecasting | 30 |
| Processes | 31 |
| Observational Techniques | 31 |
| Computing Services | 33 |
| Ocean Chemistry | 34 |
| Pollution Research | 35 |
| Climate Studies | 39 |
| Chemical Traces of Water Masses | 42 |
| Ocean Ecology | 42 |
| Plankton | 42 |
| Benthos | 46 |
| Ocean Information | 49 |
| Climatology | 51 |
| Environmental Advisory Services | 52 |
| Information Management | 53 |
| Public Information | 55 |
| Ships | 57 |
| Management Services | 63 |
| DEPARTMENT OF ENVIRONMENT | 67 |
| Atmospheric Environment Service | 69 |
| Canadian Wildlife Service | 73 |

DEPARTMENT OF ENERGY, MINES AND RESOURCES 75

Earth Physics Branch and Geological Survey of Canada 77
Director's Foreword 77
Marine Sedimentology 78
Marine Geology—Bedrock Geological Studies 82
Palaeontology 85
Multiparameter—Geophysical Surveys 86
Juan de Fuca Ridge and Offshore Mapping 87
International Ocean Drilling Project 88
Seismological Service 89
Gravity 92
Geothermal Studies 93
Geomagnetism 95
Geodynamics 98
Boundary Studies 100
Technical Support 100

APPENDICES

I. Contracts 103
II. Publications 109
III. Permanent Staff 120

# DEPARTMENT OF FISHERIES AND OCEANS

# Director-General's Foreword

In October of this year, Mike Bolton retired as Director of the Pacific Region of the Canadian Hydrographic Service located at the Institute of Ocean Sciences (IOS). He had done a great deal in the past 17 years to develop hydrography on the Pacific coast. His place is taken by Tony O'Connor who is looking forward to the challenge of continuing Mike's work. The Institute also took delivery of a new vessel, the CSS *John P. Tully*, named after John Tully, the pioneer of oceanography on the west coast of Canada. She is not a large vessel, being only 69 metres in length, but she has an extra deck which gives her an astonishing amount of laboratory space. She also carries four modern survey launches. The *John P. Tully* is the replacement for the *Wm. J. Stewart* and joins the IOS fleet as a major hydrographic and oceanographic survey vessel.

If anything could be said to characterize this past year, I would say that it is the amount of application of our work to the solution of practical problems. A great deal of our program is devoted to acquiring information about the ocean that must be obtained before some of these problems can be solved. Our largest project over the past few years has been to describe the current systems and plankton ecology of the waters over the continental shelves. The majority of the work has been completed and it has allowed our scientists to develop joint programs with the Pacific Biological Station to study recruitment and survival in selected fisheries. The information also enabled us to speak with authority at the hearings held to determine the environmental consequences of oil exploration off the Queen Charlotte Islands.

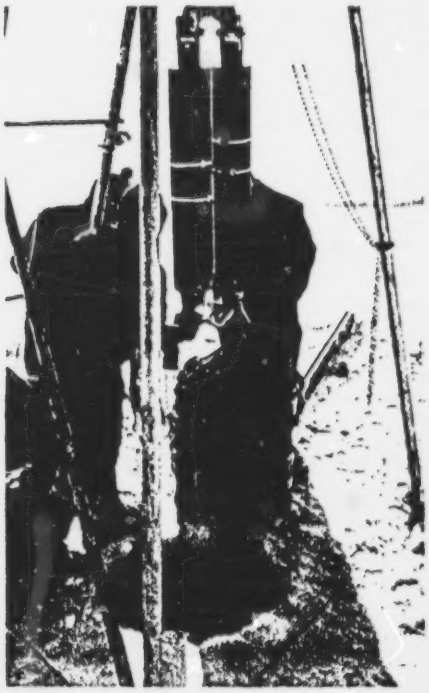
We have also been active solving problems in the coastal areas which are described in the main of the report. Our Chart Production and Distribution section had a banner year and produced two special charts; one for Expo 86 and the other of the Broken Group of Islands in cooperation with the Pacific Rim National Park. The reverse side of the latter chart depicts illustrations of marine life and includes general information relative to activities in the area. Cartography staff also produced a 29-page cruising atlas for the Jervis Inlet/Desolation Sound area.

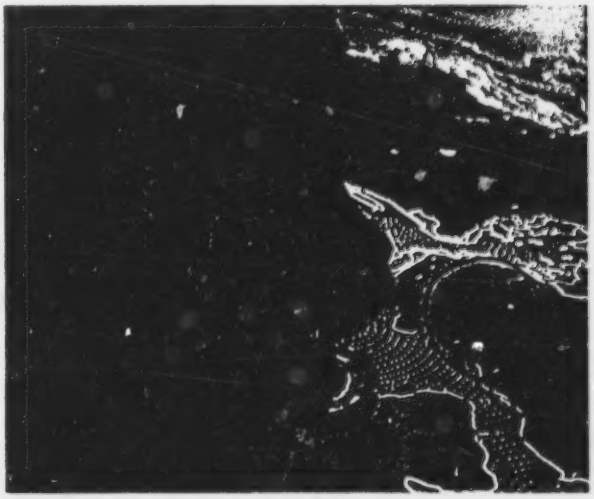
In the Arctic, our main thrust has been to upgrade our knowledge of the oceanography of the Beaufort Sea and to work with the Atmospheric Environment Service to improve ice forecasting. In 1986, using additional resources provided through the Northern Oil and Gas Action Plan, the

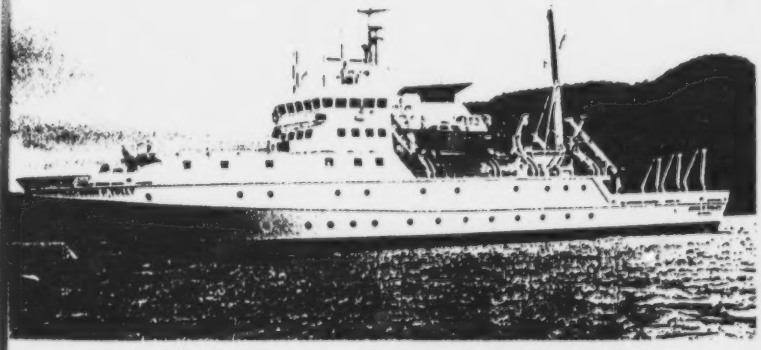
work will be expanded to include ecology and chemistry.

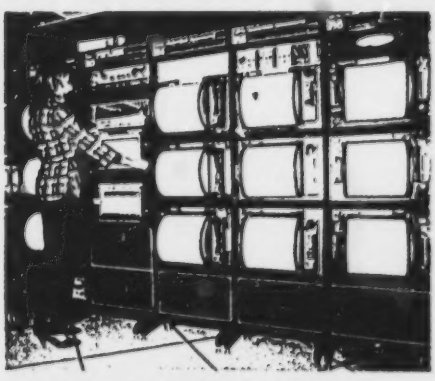
The deep-sea oceanography and modelling program we are developing for climate research has not gone as fast as I would have liked because it has not been possible to obtain additional resources. There is no doubt in my mind that this is an important line of research and that the Institute must continue with it as there is such a great potential payoff for the management of natural resources. Despite not being able to enhance the program, our scientists are making significant contributions to climate research, particularly to the problem of determining the capacity of the oceans to absorb $CO_2$.

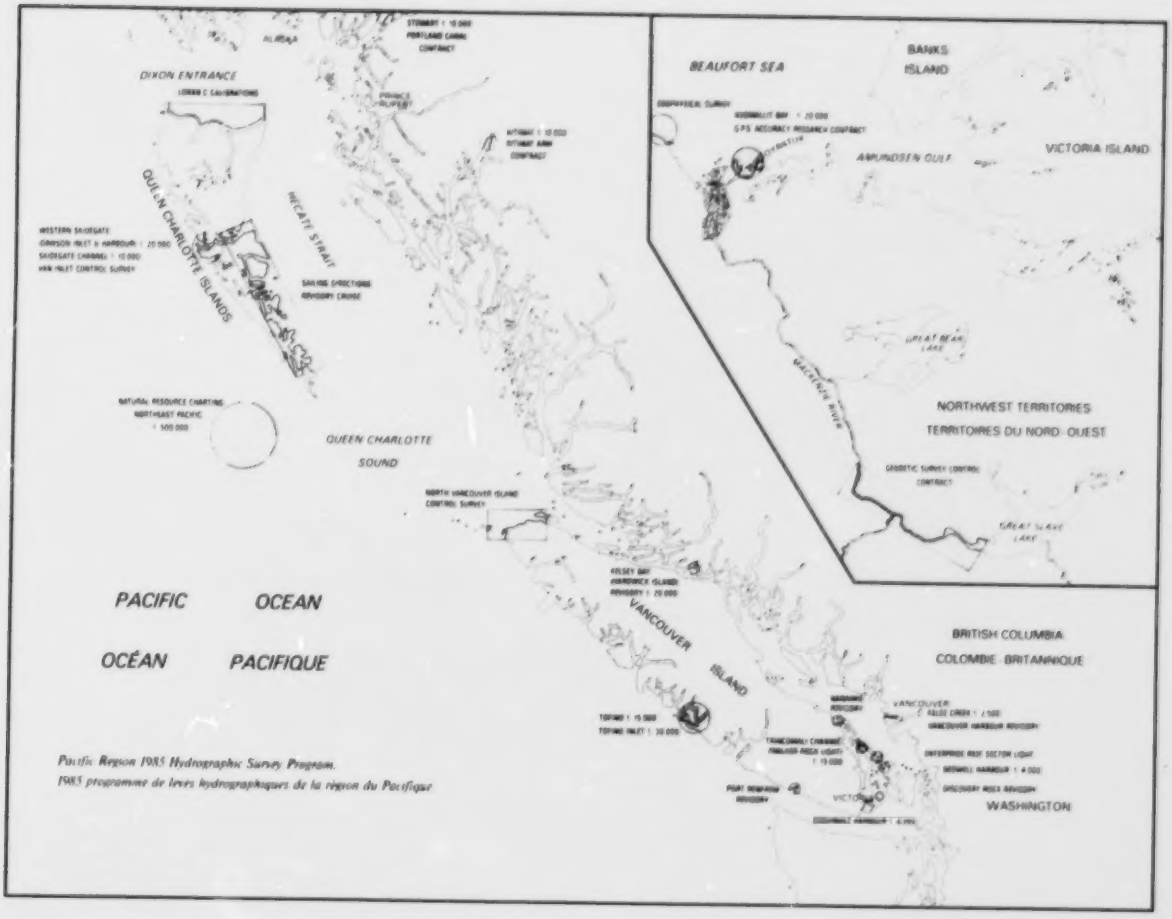
# Hydrography










DIXON ENTRANCE
QUEEN CHARLOTTE ISLANDS
HECATE STRAIT
QUEEN CHARLOTTE SOUND
PACIFIC OCEAN
OCÉAN PACIFIQUE
VANCOUVER ISLAND
BEAUFORT SEA
BANKS ISLAND
VICTORIA ISLAND
AMUNDSEN GULF
NORTHWEST TERRITORIES
TERRITOIRES DU NORD-OUEST
BRITISH COLUMBIA
COLOMBIE-BRITANNIQUE
WASHINGTON
Pacific Region 1985 Hydrographic Survey Program.
1985 programme de levés hydrographiques de la région du Pacifique

# Hydrography

The Hydrographic Division supports and conducts the field studies necessary to meet a planned publication schedule of nautical charts, tide tables, current atlases and sailing directions. The Division's area of responsibility includes the coast of British Columbia, the western Arctic and the inland navigable waters east to the Saskatchewan-Manitoba border.

Specific activities of the Division in fulfilling its mandate are reported in the following sections but perhaps the highlight of the year was the acceptance of the new research vessel, *John P. Tully*. Despite the worst ice conditions experienced in several years, this fine new ship had a successful maiden voyage to the Beaufort Sea.

Long-time Regional Director of Hydrography, Mike Bolton, retired in October, 1985; he will be missed by all Institute of Ocean Sciences (IOS) personnel.

# Field Hydrography

The Field Hydrography Section is responsible for conducting hydrographic surveys of the B.C. Coast, western Arctic and navigable inland waters in the Pacific region to ensure that requirements for navigational information are met. Alterations of, and additions to, traffic routes, types and sizes of vessels, harbours, bottom topography and coastline—all require an ongoing and resurvey program.

The major coastal survey party was assigned to the barge *Pender* from April to October. A resurvey of False Creek, the site of Expo 86, was necessitated by the removal of bridges, addition of marinas, major construction on the north shore and considerable dredging. On completion of this resurvey the barge moved to Tofino where a continuing resurvey of the area was commenced. *(Contact: G.E. Richardson.)*

CSS *John P. Tully*, on her maiden voyage, sailed for the western Arctic in July and commenced a series of surveys north of Tuktoyaktuk in the

*Barge* Pender *alongside CCG Base Kitsilano during False Creek survey.*

Kugmallit Bay area. This survey was hampered by poor ice conditions and the level of results was less than anticipated. *(Contact: B.M. Lusk.)*

At the beginning of September, the *Tully* moved west to the area Herschel Island to the Alaska/Yukon boundary to complete the geophysical portion of a multidisciplinary survey of the area commenced in 1984. *(Contact: G.H. Eaton, IOS, or S. Blasco, Atlantic Geoscience Centre (AGC).)*

CSS *Richardson* completed the survey of Skidegate Channel and resurveyed Dawson Harbour and Inlet in June and July. In August, further Loran C calibrations were carried out in Dixon Entrance. *(Contact: A.R. Raymond.)*

A resurvey of Esquimalt Harbour was commenced and several local revisory surveys were completed by IOS-based survey parties. *(Contact: F.A. Coldham.)*

Control survey work on the north coast of Vancouver Island was carried out in preparation for future resurveys. *(Contact: M.V. Woods.)*

Navigational and bathymetric support was provided for a Pacific Geoscience Centre (PGC) natural resource survey in the northeast Pacific. *(Contact: P.R. Milner.)*

Under contracts, revisory surveys of Stewart and Kitimat were completed and survey control was run on a section of the Mackenzie River.

## Hydrographic Development

Datalogging and processing hardware and software once again received significant attention. Indeed, it now appears correct to regard the annual changes as software maintenance. To this end, the logging software was modified to accept GPS (Global Positioning System) and Syledis data, and an automated range-bearing software technique was incorporated into the system. The logger software kernal was also modified to permit 32-bit addressing. Three commercial dataloggers (ISAH) were purchased in 1985, one of which includes data processing. They resulted from a technology transfer under the NRC PILP program.

A contract to improve long-range ARGO data was started with a private company, but proceeded slowly.

The laser bathymetry project (LARSEN 500) was transferred to the CHS Pacific for continued development and ultimate transfer to industry. This system, presently mounted in a DC-3 aircraft, reliably detects water depths to 30 metres in the clear Arctic waters. *(Contact: T.A. Curran.)*

## Sailing Directions

The Thirteenth Edition of the *British Columbia Coast Sailing Directions (South Portion), Volume I*, was published in January, and the Tenth Edition of the *British Columbia Coast Sailing Directions (North Portion), Volume II*, was published in July. These editions contain new information on tidal streams, vessel traffic services, Loran C and port facilities. New photography and several new diagrams were incorporated into these editions. Normally these editions are published in alternate years.

The Sixth Edition of the *Great Slave Lake and Mackenzie River Sailing Directions* was published in May. This edition contains much new information gathered on field inspection since the previous edition published in 1981. *(Contact: A. Smith.)*

Field inspection for revisions was carried out on the east coast of the Queen Charlotte Islands.

# Chart Production and Distribution

The functions of the Chart Production and Distribution Section are to ensure that survey and other pertinent data are processed for publication

as expeditiously as possible and to ensure that a ready supply is available for all users.

Eight standard new charts were produced in Pacific Region in 1985 in addition to 46 new editions, 16 reprints, 9 chart amendment patches and 11 overprint editions.

The chart amendment staff processed 1.3 million corrections on 170,000 charts.

The chart sales and distribution office distributed 159,293 charts, 76,058 publications and 42,174 information brochures during the year.

| Chart # | New Charts Released in 1985 | Scale |
|---|---|---|
| 3062 | Pitt River and/et Pitt Lake | 1:25,000 |
| 3499 | Roberts Bank | 1:15,000 |
| 3512 | Strait of Georgia, Central Portion/Partie Central | 1:80,000 |
| 3513 | Strait of Georgia, Northern Portion/Partie Nord | 1:80,000 |
| 3514 | Jervis Inlet | 1:50,000 |
| 3537 | Okisollo Channel | 1:20,000 |
| 3955 | Plans—Prince Rupert Harbour | various |
| 7600 | Beaufort Sea/Mer de Beaufort | 1:1,000,000 |

| Chart # | New Charts Produced On Contract for Publication in 1986 | Scale |
|---|---|---|
| 7661 | Demarcation Bay to/à Phillips Bay | 1:50,000 |
| 7662 | Mackenzie Bay | 1:50,000 |
| 7663 | Kugmallit Bay | 1:50,000 |
| 7664 | Liverpool Bay | 1:50,000 |
| 7665 | Franklin Bay and/et Darnley Bay | 1:50,000 |
| 7666 | Cape Lyon to/à Tinney Point | 1:50,000 |
| 7667 | Dolphin and Union Strait to/à Prince Albert Sound | 1:50,000 |
| 7685 | Tuktoyaktuk Harbour and Approaches/et les Approches | 1:15,000 |

Sixteen Notices to Shipping and 136 Notices to Mariners were issued necessitating 173 chart amendment tracings.

The Hydrographic Data Centre processed 1000 plans from government agencies, 620 Marep Reports and provided 56 survey document requests.

Much time and effort was expended in 1985 in the production of a 29-page cruising chart for the Desolation Sound area and also a special chart for Expo 86.

A special chart of the Broken Group, #3670, was produced in cooperation with Pacific Rim National Park (Parks Canada). The reverse side depicts several illustrations of marine life and includes general information relative to activities in the area.

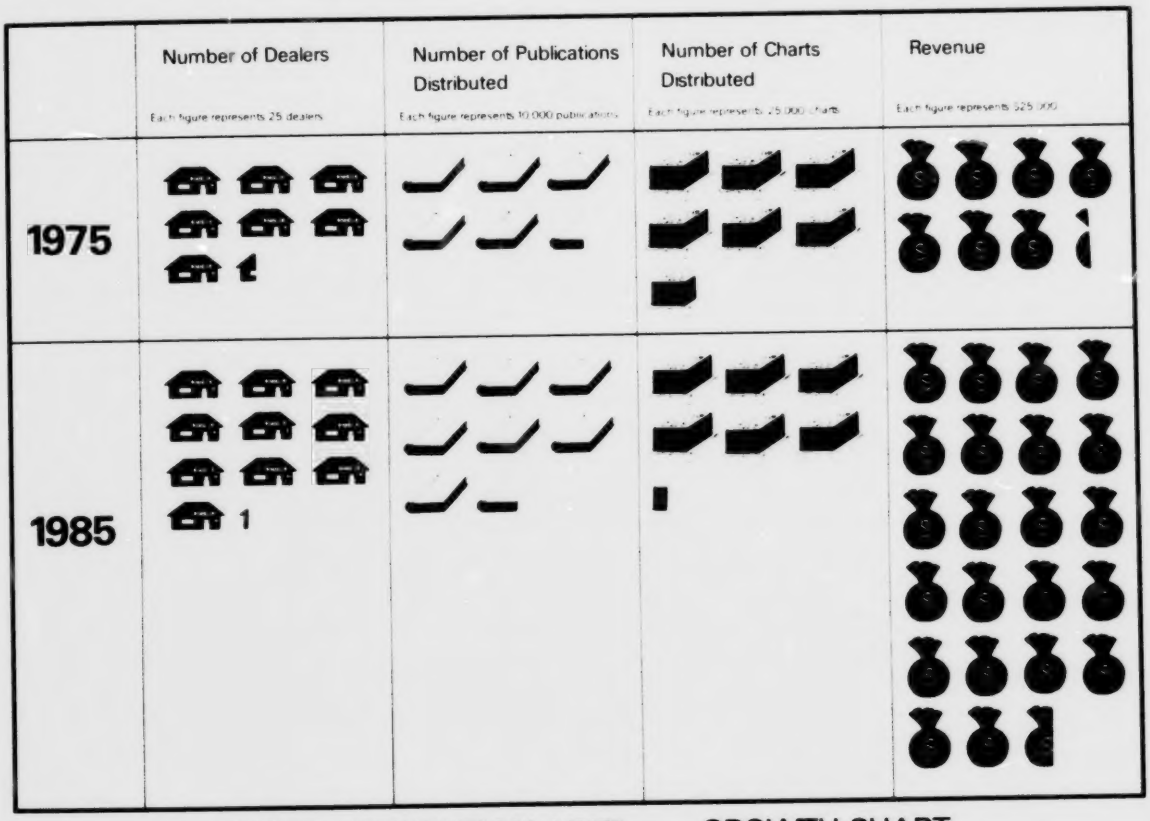



CHART DISTRIBUTION UNIT GROWTH CHART

Two senior staff successfully completed CARTO II and another two attended the Senior Cartographic Seminar at Headquarters. Nine staff members attended the Introduction to Computers course at Camosun College and two more participated in the Middle Management Orientation Training Course at IOS. Three employees successfully completed the Canadian Power Squadron's Basic Boating Course and a fourth employee completed the Coastal Navigation Course at Camosun College.

Educational and promotional activities continued with participation in the Vancouver International Boat Show, the Pacific National Exhibition and the Canadian Power Squadron's National Conference. Various tours and lectures were provided for Canadian Power Squadrons and other students.

The phototypesetter (Berthold ACS 3200) installed in October 1984 is now being utilized to produce all type requirements for the region. In automated cartography, 1985 was the most productive year to date, with a record number of digital charts being produced. The acquisition of a DMZ32HS controller, a RA81 DEC disc drive and two megabytes of memory has increased production by allowing a greater number of files to be worked on simultaneously.

## Tidal and Current Surveys

The field work for a study of the circulation in the waters surrounding the Queen Charlotte Islands was completed. All moorings in Dixon Entrance were recovered. Data are now being compiled and analyzed. Unexpectedly, strong currents (greater than three knots) were observed near Cape Chacon and Langara Island. Five additional offshore bottom-mounted tide gauges were deployed in Queen Charlotte Sound and recovered six months later, to confirm anomalies in the numerical model of Queen Charlotte Sound, Hecate Strait and Dixon Entrance. *(Contact: W.S. Huggett.)*

Current surveys in Sechelt Rapids and in Nakwakto Rapids were completed and the method of analysis refined. Much improved current predictions are now available for Nakwakto Rapids, Sechelt Rapids, Quatsino Narrows, Gabriola, Dodd, Porlier and Active Passes, and will appear in the 1987 Tide and Current Tables. These surveys will be extended to other narrow passes in 1986. *(Contact: M.J. Woodward.)*

A study of a cyclonic eddy west of the mouth of Juan de Fuca Strait was carried out jointly with the Ocean Ecology and Ocean Physics groups at IOS. A conductivity-temperature-depth (CTD) survey and a study of turbulent mixing, as well as ocean drifter studies, were undertaken. Drifter tracks are being merged with infrared satellite imagery to confirm the existence and extent of the cyclonic eddy. *(Contact: W.R. Crawford.)*

Time series observations in the Fraser River were continued with a new conductivity-temperature-depth-velocity (CTDV) meter developed at IOS. The numerical model of the Fraser was revised to include the capability to predict the tracks of objects. Observations are still being made jointly with Water Survey of Canada to measure the distribution of flow at the trifurcation point near New Westminster. *(Contact: A.B. Ages.)*

Field observations for a study of the Campbell River estuary, involving measurement of tides, currents, salinities, and temperature, were completed. Modelling of the estuary will include the salinity intrusion. This study is being carried out jointly with fisheries scientists at the Pacific Biological Station. Its objective is to discover how an environmental enhancement project carried out by B.C. Forest Products Ltd. might affect salmonid feeding grounds. *(Contact: A.B. Ages.)*

As in previous years, tidal records from 21 permanent and several temporary stations were processed and the data forwarded to Marine Environmental Data Service for archiving. Data from three gauging stations are forwarded to the Integrated Global Ocean Services System (IGOSS) each month as Canada's contribution to a Pacific mean sea level anomalies study. Tide gauges at Zeballos, Gold River, and Campbell River were operated to support a joint study with Pacific Geoscience Centre on earthquake-induced crustal movements. Planning and preliminary surveys were carried out to extend this study to Nanoose Bay and Kelsey Bay. *(Contact: F.E. Stephenson.)*

A program to obtain accurate information on tidal and long-term water level variations in Baffin Bay and along the Arctic coast of the Queen Elizabeth Islands was continued. This program will end in 1986. The data are expected to provide information on seasonal and annual variations in net transport through the Arctic Archipelago. *(Contact: F.E. Stephenson.)*

Two tsunami warning gauges, at Langara Island and at Tofino, were maintained and operated on a routine basis. The tide gauge station at Bamfield was modified to serve as a third tsunami warning gauge. It is now operating satisfactorily and is capable of transmitting information directly to the Tsunami Warning Centre at Honolulu, Hawaii.

A successful tsunami conference was held at IOS, sponsored jointly by Hydrography and Ocean Physics. The conference consisted of a Workshop on the Technical Aspects of Tsunami Analysis, Prediction, and Communications; the tenth meeting of the International Coordination Group for the Tsunami Waning System in the Pacific; and an International Tsunami Symposium sponsored by the Tsunami Commission of the International Oceanographic Commission (IOC). *(Contact: W.J. Rapatz.)*

## Diving Unit

During 1985, 60 dives were carried out by the Diving Unit in support of activities at IOS. Diving activities can be summarized as follows: recovery of bottom-mounted tide gauges from sites in Dixon Entrance; inspection and/or servicing of the stilling wells, tide staffs and their supporting structures at tide stations on the Pacific coast; annual servicing of the permanent tide gauge network in the western Arctic; tests of survey launch noise conducted in Saanich Inlet; dives to inspect the propellors, zincs and/or transducers of IOS ships as well as a survey of the *John P. Tully*'s bottom paint; underwater modifications to an electronics test facility at the IOS wharf; observation of a trial of a through-ice deployment technique and recovery package for tide gauges; clearing the starboard propellor of an American pleasure boat which became fouled in an IOS mooring in Patricia Bay; and, training dives.

Some of our diving requirements in the Arctic (at Tuktoyaktuk and in the Queen Elizabeth Islands), to service tide gauges, were again carried out under contract. *(Contact: F.E. Stephenson.)*

# Engineering Services

Engineering Services provides electronics and mechanical engineering and electronics support for hydrographic surveys; oceanographic research and ship operations; and an industrial liaison service promoting interaction between IOS, other government departments, and the private sector. *(Contact: T.A. Curran.)*

## Engineering Development

This group provides custom development of hydrographic and

oceanographic instrument systems and consultations to all IOS groups.

Instrumentation projects under development in 1985 included a telemetering tide gauge, a Meteorburst tidal telemetry system, and development of a turbidity sensor.

The Active Drifter system underwent two offshore tests which were reasonably successful. Data were collected on the self-navigation performance.

Development of acoustic expertise continues to be a priority with Engineering Development. Standard modules are being constructed for basic signal processing tasks. Two competitive transducers were purchased to attempt to improve depth capability of the Skipper sounders. A narrowbeam acoustic telemetry project achieved rapid development this year. Slow-scan television pictures were transmitted over an acoustic link, and were the subject of a paper at Oceans 85 and three local seminars.

The SAIL system was installed on the *Tully* during the past year. A management decision was taken that ongoing accountability for proper operation of these systems will permanently reside within the group.

Several annoying electromagnetic interference problems in our launches were tackled toward the end of 1985. Some solutions are in hand, but others are still under development.

Contract supervision by the group included the Correlation Current Meter (now into the final phase), an acoustic release contract, a fibre optic refractometer, and completion of a laser diode pressure sensor. The latter contract did not achieve specifications, but led the company to two spinoff contracts. *(Contact: J. Galloway.)*

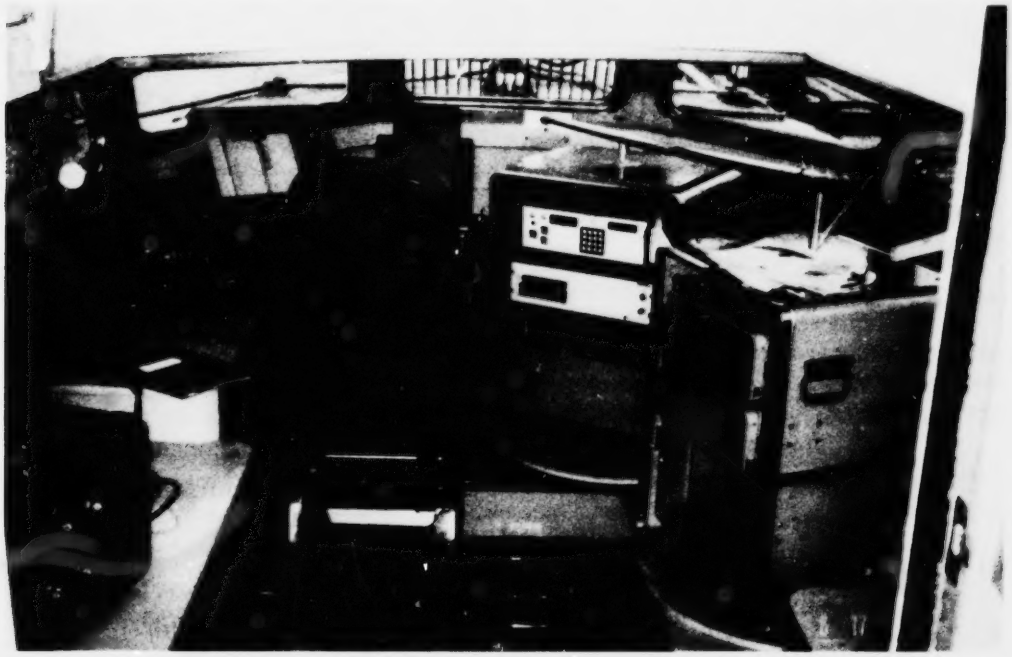
## Institute Electronics

Calibration, repair, installation and routine maintenance of equipment in support of hydrographic and oceanographic programs and ship operations were successfully performed during the year. The major equipment areas were radios, depth sounders and digitizers, positioning systems and data loggers.

In the communications areas, approximately 69 VHF-FM and 15 HF/SSB transceivers were maintained. A remote display for the teletype over radio link (TOR) was established in the Regional Ship Superintendent's office for direct hardcopy communication with IOS vessels. The Glenayre

message terminal system has proven very satisfactory and has been extended to six units.

The sonar group maintained 28 survey-type and navigational depth sounders, as well as numerous small digital sounders and 12 sounder digitizers. In addition, two velocimeters were serviced and maintained.

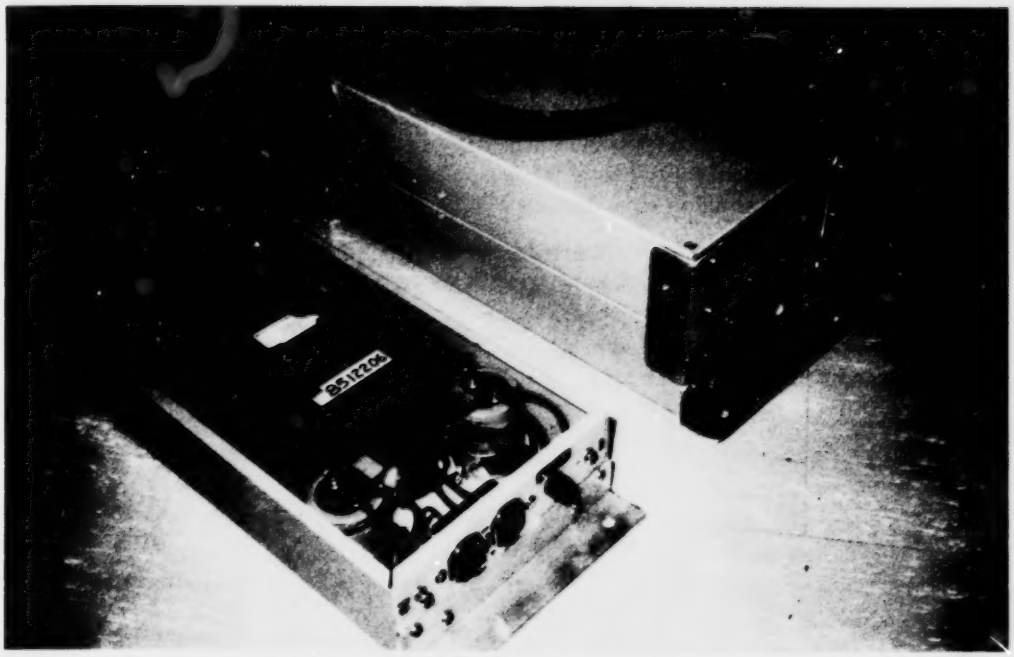


*A typical configuration of electronics for inshore hydrographic survey. From port to starboard: distance measuring unit (DMU), VHF radio, Skipper echo sounder, monitor and HAL (hydrographic acquisition and logging) system keyboard, Qantex data storage and tape drive unit (top), MSI depth digitizer, HAL, and ARGO positioning system including the receiver, range positioning and control display units.*

Approximately 21 microwave positioning units, 15 Argo units, two transit satellite navigation systems and several Loran C and Omega systems were serviced.

The five in-house datalogging systems (HAL) continue to provide excellent performance, and received routine hardware and software maintenance. Three commercial ISAH dataloggers/dataprocessors were acquired over the past year; they performed well.

Ships, launches and the barge *Pender* were fitted out for hydrographic purposes.



*A filter, designed and installed by Institute Electronics, to reduce electromagnetic interference on launch installations.*

Field support was provided for hydrographic survey on *Tully*, and local support was provided to local survey parties.

Continuing support was provided to Computing Services in the maintenance of the Kongsberg drafting system. *(Contact: W.R. Taylor.)*

## Industrial Liaison and Contracting

IOS has an established policy of contracting out a significant portion of its program to the private sector. Liaison and support for contracting activities is conducted by the administrative staff of Engineering Services.

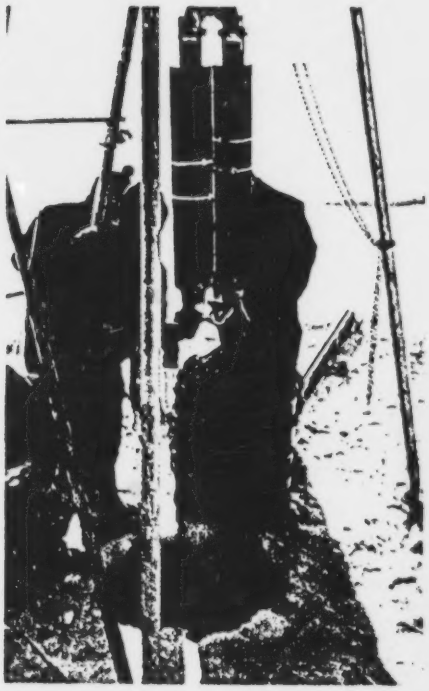
In addition to contracting out directly, IOS participates in such government ventures as the Unsolicited Proposals (UP) program with the Department of Supply and Services (DSS), and both the Program for Industry/Laboratory Projects (PILP) and the Industrial Research

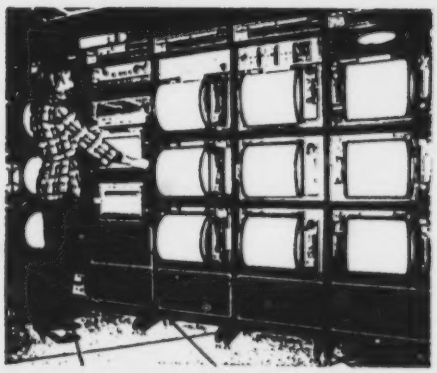
Assistance Program (IRAP) with the National Research Council (NRC). IOS was involved to some extent in 116 contracts in the past year, ranging in value from less than one thousand dollars to approximately one million dollars, and with a total value in excess of $4.8 million.

The NRC programs PILP and IRAP were consolidated under the IRAP name during the past year. Consequently, IRAP activities span the range from transfer of technology from government labs (including IOS) to labour-cost sharing agreements.

Increasingly, there is concern from the private sector regarding manufacturing rights and protection of fundamental technology developed in the labs. The crown corporation, Canada Patents and Development Limited, can provide this assurance and IOS is presently transferring administration and control of several technologies to CPDL. *(Contact: T.A. Curran.)*

# Oceanography





# Ocean Physics

## Fjords and Channels

In addition to continued work aimed at understanding and predicting the distribution of properties within fjords on the basis of external inputs, 1985 saw the first of a series of field programs to study the nature of mixing in tidal fronts. Simultaneous measurements of turbulent energy dissipation and vertical velocity were obtained in a tidal channel, which showed that the maximum turbulent dissipation was located well behind the front, even though the front contained downward vertical velocities as high as 40 cm/sec, which carried air bubbles to depths of 50 m. *(Contact: A.E. Gargett, D.M. Farmer.)*

## Straits

The extension of the two km mesh vertically integrated barotropic tidal model to cover the whole of the Georgia Strait/Puget Sound/Juan de Fuca Strait system was completed. After calibration, the model was used to generate tidal constituents for each grid point. These were then incorporated in a personal computer tidal current prediction program, developed by a contractor with IOS assistance. This has been delivered to the Environmental Protection Service and Canadian Coast Guard for use in real-time prediction of tidal currents in emergency situations. *(Contact: P.B. Crean.)*

The extension of the barotropic tidal model also permitted improvements to the "Fraser River plume" surface layer model. These improvements, and the addition of wind forcing, brought this model to the point where it is now capable of reproducing observed drifter tracks in all seasons. *(Contact: P.B. Crean.)*

The last of the current meter arrays deployed in the passages of the Arctic Archipelago were recovered in April. In the last three years a total of 66 current meter records and 15 bottom pressure records have been obtained. Of these, eight current records and four pressure records are of 12-month duration. The reduction and analysis of this data in terms of tides and mean flow was begun, together with that of the water property surveys conducted during current meter deployment and recovery. Work

is proceeding on a triangular grid tidal model for the channels making up the Northwest Passage, with completion expected early in 1986. *(Contact: H. Melling, T.S. Murty.)*

The first of two cruises to Gibraltar Strait was conducted in November, in cooperation with U.S. scientists on a U.S. vessel. The internal structure was mapped using acoustic techniques in conjunction with more conventional means. The objective is to test the theoretical conclusion that the exchange between the Mediterranean and Atlantic, which determines the properties of the Mediterranean, is controlled by the same internal hydraulic mechanisms as control the exchange over the sills in many B.C. fjords. *(Contact: D.M. Farmer.)*

## Continental Shelf

The last phase of the field work in a 10-year program to obtain a basic description of oceanic conditions on the Pacific continental shelf was concluded with the recovery of the last moorings from the shelf west of the Queen Charlotte Islands in November. Data from earlier phases of the survey, off Vancouver Island and in Queen Charlotte Sound, have already yielded numerous publications and generated process-oriented experiments. The information was also used as the basis for presentations to the West Coast Offshore Exploration and Environmental Assessment Panel hearings. The general picture is one of complex flow patterns created by the interaction of large tides, rugged bottom topography, and seasonal variations in winds and coastal runoff. Off Vancouver Island the spatial pattern of tidal frequency currents is controlled by continental shelf wave dynamics. Vorticity associated with shear between offshore wind-drive flow and nearshore buoyancy (runoff)-driven flow generates a semi-permanent eddy locked to the bottom topography off the mouth of Juan de Fuca Strait. Further north, intensification of this shear by Brooks Peninsula results in eddy generation by baroclinic instability. In Queen Charlotte Sound, eddies are generated by the interaction of tidal currents with bottom topography. Whatever their origin, these eddies are the main contributor to the exchanges between the continental shelves and the open ocean offshore. *(Contact: R.E. Thomson, H.J. Freeland, W.R. Crawford.)*

A mooring array designed to measure the vorticity balance of the large eddy previously observed at the mouth of Juan de Fuca Strait was maintained for three months during the transition between winter and summer conditions. Although the vorticity was nearly constant during the latter part of the period, the closed streamlines of the eddy were

observed for only a portion of the time. *(Contact: H.J. Freeland.)*

A project designed to improve predictions of surface drift on the west coast of Vancouver Island, for use in developing search and rescue plans, was conducted jointly with the Canadian Coast Guard over the last two years. Satellite surface drifters were used to build up a data base, which was, in turn, incorporated in a predictive model by the contractor conducting the project. It is planned to extend this work to other areas as funds permit. *(Contact: R.E. Thomson.)*

Numerical models combining continental shelf dynamics, topography and simple models of plankton growth and nutrient transfer have been developed and time-lapse movies of the output constructed. They qualitatively reproduce many of the features seen in satellite water colour images of the Pacific Coast. The importance of various parameters can be estimated by varying them in the model. *(Contact: G. Holloway.)*

A current meter array was installed on the outer continental shelf in the Beaufort Sea, to complement earlier measurements and to determine whether the expected eastward jet exists over the shelf break. This current is suggested by water property distributions and various theoretical ideas. Numerical and theoretical studies of the current patterns on the Beaufort shelf indicate that topographic effects are very important. *(Contact: H. Melling, W.P. Budgell.)*

Images of the ice cover from satellite radiometers and airborne SAR are being collected and compiled. Where sufficient continuity exists, time-lapse animation sequences were compared. Ice motion vectors have been extracted from the imagery for use in estimation of the spatial and temporal correlation scales of ice motion. These statistics determine the limits of predictability, as well as suggesting which processes are most important in controlling ice motion. *(Contact: J.F.R. Gower.)*

A variety of techniques were used to obtain information on the details of the flow field under a pressure ridge keel. The form drag on such keels is thought to be the major source of coupling between ice and water, but existing parameterizations do not correctly represent the physical processes involved, particularly when the water column is stratified. A two-dimensional numerical model was developed for use in planning the experiment and interpreting the results. *(Contact: D.R. Topham.)*

Ice growth on the continental shelf forms dense brine which then drains across the shelf. The rate of brine drainage can limit ice growth, while the associated flow field is an important element of the winter circulation. The parameters controlling this process are being studied by

means of laboratory models. In addition it has been found that the pressure dependence of the freezing point of sea water implies that deep ice protrusions should melt, creating supercooled water which can then freeze on the bottom of thinner areas. The implications of this for the growth of ice sheets are being assessed through laboratory studies and theoretical calculations. *(Contact: D.R. Topham, E.L. Lewis.)*

## Deep Sea

In September, an array of moorings carrying sediment traps, current meters and transmissometers was deployed near a known hydrothermal vent plume field on the Endeavour Ridge segment of the Juan de Fuca Ridge, in cooperation with the Geological Survey of Canada and Oregon State University. A CTD survey was conducted and water samples were collected. A towed body carrying a CTD and transmissometer detected the plume about 10 km from the ridge. These moorings are to be recovered in July of 1986. *(Contact: R.E. Thomson.)*

Three climate monitoring cruises to Ocean Station P (50°N, 145°W) were conducted in 1985. The data collected by the weatherships at this station between 1948 and 1981 were reviewed. Evidence of significant variations at depths as great as 3500 m was found, indicating responses of the overall circulation to variations in atmospheric fields. *(Contact: S. Tabata.)*

Experiments with various idealized basin-scale ocean models continued. The model developed by the Geophysical Fluid Dynamics Laboratory in the U.S. was obtained and installed on the Atmospheric Environment Service's (AES) Cray computer at Dorval. *(Contact: G. Holloway.)*

## Forecasting

After numerical storm surge models indicated that the hypothetical "100 year storm" based on extrapolations of meteorological data would generate a surge which would flood most of Tuktoyaktuk, a survey of driftwood around the town was conducted in an attempt to gather better information on the actual incidence of extreme water levels. This is being extended to other areas in the Beaufort Sea, in cooperation with Environment Canada. *(Contact: R.F. Henry.)*

As part of a project sponsored by the World Meteorological Organization, a workshop on storm surges was organized in Bangladesh in December. The primary focus of the workshop was the importance of collecting reliable and quantitative observations of storm surges when they occur,

as such data is essential for the calibration of numerical models. Such models already exist, and could be used for predictions and warnings if accurately calibrated. The workshop was attended by meteorologists and coastal authorities from Bangladesh, Burma, Sri Lanka, Pakistan and Korea. *(Contact: R.F. Henry, T.S. Murty.)*

The effect of bottom roughness of deep ocean tsunami travel times was determined using a new theoretical model incorporating a statistical description of bottom topography. The potential response of Georgia Strait to local earthquakes was examined using the two km vertically integrated numerical model. *(Contact: G. Holloway, T.S. Murty.)*

In response to the recommendations of the inquiry into the loss of several fishing vessels in a storm on October 12-13, 1984, a number of activities designed to contribute to improved coastal weather and sea state forecasting were begun in cooperation with the Atmospheric Environment Service and the Canadian Coast Guard. These included a study of the impact of new observations on coastal sea-state forecasts, the continuation and up-grading of the coastal wave buoy network, and the groundwork for a new network of offshore meteorological buoys. *(Contact: J.F. Garrett.)*

## Processes

A two-dimensional numerical model of the evolution of double diffusive instabilities was developed on a local contractor's VAX-730 array processor computer system. This permits calculations with a resolution greater than that readily achievable on much larger machines. The model is being used to study the interaction of double diffusive instabilities with velocity shears such as might be created by internal waves. Such work is essential to the eventual development of an accurate parameterization of small-scale processes for use in ocean circulation and climate models. *(Contact: G. Holloway.)*

## Observational Techniques

The Fluorescence Line Imager (FL1) is a programmable multispectral imager developed by contracts with funding from DFO and the Interdepartmental Committee on Space. The prototype has been flown over land, lakes and the ocean, and has demonstrated that the performance objectives are achievable. In addition to the flight program, work this year has focussed on the analysis and interpretation of the

data collected and planning for demonstrations in Europe and China. *(Contact: J.F.R. Gower.)*

A variety of acoustic remote sensing techniques for oceanic measurements are under investigation. Passive methods for determining wind speed and direction, precipitation, and ice strain by measuring sound levels in various frequency bands all show promise. Theoretical and experimental work is continuing in cooperation with the University of Victoria, various U.S. agencies and local contractors. These focus on the details of the sea surface processes which generate the noise. An observing system combining noise recordings with sea surface imagery obtained with both video and high frequency echo sounding was developed and tested for use in the FASINEX experiment, early in 1986. Development of an operational wind speed sensor for buoy use was begun. *(Contact: D.M. Farmer.)*

Several projects using back-scattered acoustic signals were also conducted. These include studies of the measurement of the vertical profile of sound speed (and hence temperature or salinity), correlation sonar measurements of ice and water motion, and measurements of the directional spectrum of ocean waves from a bottom mounted array. *(Contact: D.M. Farmer.)*

The most exciting acoustic development of 1985 was the demonstration that the scattering of acoustic signals transmitted across a tidal channel could be used to measure the flow in the channel. This has great potential for measurements in areas where conventional techniques are difficult, such as channels with very strong currents or active shipping. *(Contact: D.M. Farmer.)*

The small solar powered robot vessel known as the "Active Drifter", was tested at sea several times during the year. Its ability to maintain speed and heading in moderate sea conditions appears to be about the same as in smooth water, and the performance of the solar array is not adversely affected by motion and spray. The stresses associated with buoy motion in the wave field are large, however, resulting in a burnt-out motor on one trial. Tests are continuing, along with the commercial development of the station keeping buoy and experiments with a simple retrofit package for ordinary meteorological drifters. *(Contact: J.F. Garrett.)*

# Computing Services

The principal activity during 1985 for Computing Services was the design and acquisition of a new computer. This will be added to the Central Computer Systems complex during 1986. Considerable attention was placed on designing the most cost-effective configuration for Phase I implementation and on plans for additional equipment and software for Phase II. This latter phase is scheduled for 1987-88. The final configuration for Phase I will be a VAX 785 processor with 16 MB main memory and floating point accelerator; 1.3 Gb disk storage; two 1600/6250 bpi tape drives; one laser printer, and three line printers. To complement this hardware, a number of programmer productivity aids were evaluated and specified during 1985, for inclusion in the VAX package. Among them were the full-screen editor, and a comprehensive graphics package which offered many new application-oriented features and extensive device support.

Design work during 1985 also included a tentative layout for an Ethernet local-area network to connect the new VAX processor with other VAX computers on-site. It is anticipated that this network will be installed during the Spring of 1986. The Gandalf PACX network for async devices continued to expand during the year, with the addition of new terminal and remote computer port connections. The network now supports a mixture of 84 terminals and personal computers, and 48 mainframe and minicomputer ports, including access to DATAPAC and BC tel dial lines.

The Sperry mainframe continued to perform at full capacity during the year, with no changes to either hardware or system software. The NAG and IMSL numerical subroutine libraries, however, were upgraded during this time frame.

Computing Services also completed work on the HP flat-bed plotter support for the Sperry, and the design and initial implementation of the conversion of the IOS plotting software from the Sperry to the VAX.

By Spring of 1985, IOS access to the CRAY-1S at AES Dorval via DATAPAC got underway. After an initial learning period, much productive work was accomplished, leading to a peak utilization of 6.4 hours during October. Over the nine month period from April to December, two users clocked a total of 27 hours of CRAY time. The primary use of the CRAY supercomputer during 1985 was for large-scale ocean models to study climate and perform ice predictions. It is anticipated that the

requirement for this type of facility will increase significantly over the next few years, as more emphasis is placed on climate research, wave forecasting, and in joint programs with AES.

The acquisition of personal computer workstations for research, word processing, spreadsheet and database applications continued during 1985; 16 new PCs were added. Some of these systems were taken onboard ships for the first time, with considerable success. *(Contact: R.E. Johns.)*

# Ocean Chemistry

Research was focussed on two major areas: the oceanic capacity to absorb $CO_2$ and other climatic gases, and to accept societal wastes of metals and petroleum pollutants. Pollution research addressed regional issues of disposal of mine tailings in Alice Arm, the dumping of contaminated sediment from False Creek (Vancouver) and the study of metal-binding proteins in coastal polychaetes compared to those in palm worms collected at hot vent sites. Ocean climate studies were concentrated on $CO_2$ through atmospheric monitoring in cooperation with Atmospheric Environment Service at Downsview; an extensive oceanic monitoring in the Pacific Ocean on the container carrier, *Lillooet*; IOS cruises to Ocean Station P (50°N 145°W) and $CO_2$ modelling. Related to the $CO_2$ removal process, an ocean flux program, in cooperation with Woods Hole Oceanographic Institution, using moored sediment traps, yielded a valuable time-series on fluxes of material, carbon, carbonate, nutrients and metals at Station P. Chemical tracers were applied to identification of both open-ocean and coastal-water masses and successes were evident for tritium, lead isotopic ratios and freons. Again in cooperation with Atmospheric Environment Service, a long-term study on background acidity of marine rain and aerosols, its distributions and causes, was initiated with the buildup of an acid-rain laboratory and shipboard program.

Funding by the International Development Research Centre (IDRC) made it possible for IOS scientists to conduct enclosure experiments in Xiamen, P.R. China and for Chinese scientists to participate in the SEAFLUXES enclosure work at IOS. Mr. Zheng Jiancheng has been our resident visiting scientist on $CO_2$ for the second year. Five other scientists, from the Third Oceanographic Institute, Xiamen University, Shandong College of Oceanology and the Dairen Institute of Marine Environmental

Protection, visited for terms of three months. U. Schwarz from the Department of Chemistry at the University of Victoria was completing her thesis study on freons at IOS. Additional projects were carried out with the University of Miami, Scripps Institution of Oceanography, Pacific Marine Environmental Laboratory of the National Oceanographic and Atmospheric Administration (NOAA), the Department of Oceanography at UBC and the Environmental Protection Service. Dr. G. Branton spent his sabbatical at IOS working on a cooperative fibre-optics study.

$CO_2$ and climatic gases are concerns that are global in nature, and research on the chemical aspects must be international in scope. These climatic studies will be carried out under various international programs, such as the World Climate Research Program and the Background Monitoring Network, which are in effect or being formulated by the Scientific Committee on Oceanic Research (SCOR), Committee on Climate Change and the Oceans (CCCO), World Meteorological Organization (WMO), International Council of Scientific Unions (ICSU) and Scientific Committee on Problems of the Environment (SCOPE).

# Pollution Research

## Alice Arm

The study of mine tailings dumping in Alice Arm was in its final stage with publications and reports being written. Profiles of Pb-210 and metals in core samples, and sediment trap results indicated a strong effect of tailings dumping on the sedimentation rate, by as much as double, 8 km from the outfall. The study of nutrients and density of water movement suggested that convective replacement in the winter was the dominant process while in Observatory Inlet and Hastings Arm, downward diffusion renewed the two basins during the summer and early fall. *(Contact: R.W. Macdonald.)*

Trace metals in the water column were also utilized to identify water masses in the Alice Arm and Portland-Observatory Inlets. Using the clean room technique and mass spectrometric analysis, accurate levels of very low lead concentrations (ng or sub ng $kg^{-1}$), as well as cadmium and zinc, were obtained. Isotopic and concentration data of lead were used to identify water masses and sources: the major fluvial input, the mine tailings and deep, shelf waters. In particular, the deep, shelf waters with ultralow lead and less radiogenic isotopic ratio flowed in through Portland and Observatory Inlets to renew the bottom fjord water in Alice Arm. *(Contact: C.S. Wong.)*

Investigation of metal levels in the biota and pore waters following mine closure in 1982 were also continued into 1985. In cooperation with DFO's Habitat Management Division, a report on the metals and metal-binding proteins in the Golden King Crab, *Lithodes aequispina*, from the Alice Arm-Hastings Arm area has been completed. A study of the particulates in the gills of the crabs showed statistically an increase of lead burden in the gills of the specimens from the polluted Alice Arm, but undetectable in Hasting Arm samples. Examination by scanning electron microscopy (SEM) and energy dispersive X-ray (EDX), in cooperation with University of Victoria, indicated the absence of particles with high lead, molybdenum or zinc associated with sulfide minerals in the ore body. Particles that were silicons in nature were qualitatively identified as detrital clay. The work suggested the high lead burden to be intercellular and to be taken up through the gills in the dissolved phase. *(Contact: J.A.J. Thompson.)*

*Golden King Crab,* Lithodes aequispina, *collected from the Alice Arm-Hastings Arm area, and found to have an increase of lead burden in the gills due to uptake from seawater.*

## Metal Binding Protein

A study of the metal binding protein in the nephtid polychaete from the tidal flats of Patricia Bay and the amphoretid polychaete, *Paralvinella palmiformis* (palm worm), a scarce species collected at hot vent sites in

1983-4, was conducted in cooperation with the Biology Department of University of Victoria. A polarographic technique was used to detect the metal-binding protein using the more abundant polychaetes from the tidal flats, then applying it to the scarcer palm worm. Arsenic, boron, zinc, copper, vanadium and cadmium were found to be within the levels found in other classes of marine biota. Studies of mucal excretions from the palm worms showed that uranium reached nearly 300 mg $kg^{-1}$ in this material, suggesting its possible accumulation through absorption from the water column. Such studies on metal and protein were among the first being carried out on hydrothermal vent biota. *(Contact: J.A.J. Thompson.)*

## Ocean Dumping

False Creek was the site of extensive dredging as part of the preparation for Expo 86. The sediments dredged from False Creek had high levels of cadmium (1.5 to 40$\mu g\ g^{-1}$) and of lead (200-800$\mu g\ g^{-1}$) and the flux of metals from sediment to sea water column was a matter of concern. Enclosure experiments were conducted to determine whether this flux could be reduced by covering the contaminated sediment with a layer of clean material (capping) at the disposal site.

A specially constructed catamaran barge with 1500 L polyethylene-lined fiberglass tanks was used to study the sea water-sediment interactions, metal release and capping with a clean alluvial material. The metal analysis was done by isotope dilution method using the unique clean room and mass spectrometer at IOS. The cadmium concentration of sea water in contact with the contaminated sediment or with the alluvial capping material (cadmium less than 0.3$\mu g\ g^{-1}$) doubled. When False Creek sediment was capped with the alluvial material, the concentration in the overlying seawater rose to four times its initial level. This work suggested capping to be ineffective for cadmium; the increase in cadmium in sea water could be accounted for by a release of only 0.06 per cent of the sediment-bound cadmium. Lead in this experiment behaved differently. The capping material did not release lead to the sea water, and appeared to reduce the release of lead from the contaminated sediment by about 50 per cent. The maximum lead release occurred during the first week of the experiment and could be accounted for by only 0.001 per cent of the sediment-bound lead.

A different enclosure experiment was conducted on a much larger scale: 15 cm of False Creek sediment in contact with 70,000 L of sea water. An entirely different metal behaviour was observed in the water column of

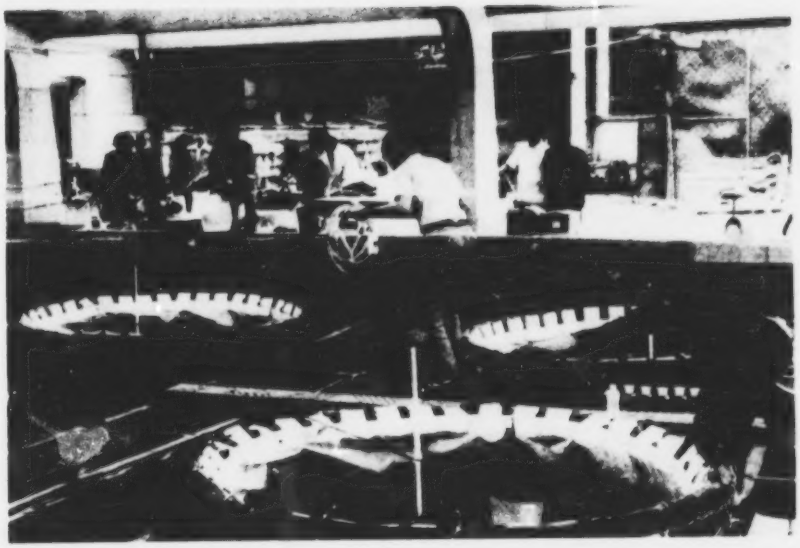
18 m compared to the shallow 1 m depth of the catamaran containers. A vertical concentration gradient for both cadmium and lead developed. The sea water maxima (600 ng $kg^{-1}$ for each metal) occurred at a depth of 13 m, due to the effects of adsorption closer to the sediment. Such investigations point to the rudimentary nature of our knowledge of metal dynamics in sediment/sea water interactions and the difficulties in formulating regulations based on scientific observations. *(Contact: C.S. Wong.)*

## Canada/China Cooperative Experiments

A series of marine ecosystems enclosure experiments (MEEE), funded partially by the IDRC, was carried out at Patricia Bay and in Xiamen, P.R. China, with the participation of IOS, the Department of Oceanography at UBC, the Third Oceanographic Institute, Amoy University at Xiamen and the Shandong College of Oceanology at Qingdao. A team of eight Canadian scientists joined their Chinese colleagues in May in an experiment using enclosures of plastic bags inside a large, shaded stone-walled pond in Xiamen. A clean laboratory was also constructed at the Third Institute for the metal analysis. The lab was supervised by a Chinese scientist trained at IOS through IDRC funding. Heavy metals (copper, cadmium, mercury, zinc and lead) and sediments from the discharge of a fertilizer plant in Xiamen were added to the enclosures. Chemical and biological events were followed for a month. From July to September, five Chinese scientists participated in an experiment at IOS using a specially-constructed catamaran barge, fitted with foam flotation blocks and fiberglass tanks measuring ½ m x 1 m. Release rates for metal (cadmium, copper, lead and zinc) and biological events were followed for sediment/sea water interactions under simulated conditions of (a) sea water in sunlight, (b) sea water/sediment in sunlight, (c) sea water/sediment with no sunlight, (d) sea water/sediment with high silt loading, and (e) sea water/sediment in an anoxic environment. False Creek sediments were used. Anoxicity and the presence of sulfide removed the metals effectively. The sea water in contact with the sediment doubled its cadmium level and increased the copper level by a factor of six during the 24 day period. *(Contact: C.S. Wong.)*

## Hydrocarbons

The report of the international Baffin Island Oil Spill Experiment (BIOS) was completed with the chemistry section under the chairmanship of



*The enclosure configuration at the 3rd Institute of Oceanography, Xiamen, China, conducted as part of an IDRC-funded China/Canada pollution experiment.*

Walter Cretney of IOS. Laboratory methods were being updated for the upcoming NOGAP sampling program. *(Contact: W.J. Cretney.)*

Planning was undertaken for the Northern Oil and Gas Action Plan (NOGAP). A field program is planned for 1986-88 and coordination of the research will rest with Ocean Chemistry. *(Contact: R.W. MacDonald.)*

# Climate Studies

## $CO_2$, Climatic Gases

The Marine Carbon Research Centre at IOS, now in its seventh year, has shifted its focus from atmospheric $CO_2$ monitoring to oceanic $CO_2$ problems by conducting research, monitoring and modelling of $CO_2$ and the biogeochemical carbon cycles. The Centre participated in developing an international network by taking a lead role in conducting the third meeting of SCOR Working Group-75 on Oceanic $CO_2$ Methodology held at Les Houches, France in September. The meeting was attended by 15 SCOR-WG members and invited experts to review plans for a world-wide program to measure oceanic $CO_2$. In October inputs were provided to CCCO through participation as a member of its $CO_2$ Panel. The first

meeting at Woods Hole Oceanographic Institution produced the justification for a world carbon program for consideration as elements of major global prógrams such as the World Ocean Circulation Experiment (WOCE), Tropical Ocean and Global Atmosphere (TOGA), and the Global Ocean Flux Study (GOFS); currently in the planning stages.

The atmospheric $CO_2$ monitoring program as part of World Meteorological Organization (WMO) background network, was carried out as a joint effort with Atmospheric Environment Service (Downsview, Ontario). Air samples from Alert, Sable Island and Cape St. James were sent to IOS for analysis of seasonal changes and secular rise of $CO_2$ in the atmosphere. A unique $CO_2$ calibration laboratory, equipped with a Caltech cathetometer capable of pressure measurements to ±0.002 mm in height in a room with temperature controlled to ±0.01°C, was built as an alternate facility to the Scripps WMO Central Laboratory. The IOS laboratory will serve as the Canadian national standards laboratory for $CO_2$ measurements and also for the development of oceanic $CO_2$ standards for global ocean monitoring.

The oceanic $CO_2$ monitoring program was based on sampling from the *Lillooet*, a container carrier running between Brisbane in Australia, Noumea in New Caledonia and Richmond, B.C., and IOS quarterly cruises to Ocean Station P (50°N 145°W). Very large seasonal amplitudes in partial pressure of $CO_2$ ($pCO_2$) were observed in different oceanic regimes: the subarctic, sub-tropical and even the equatorial Pacific waters. Compared to published historical data from the late 1950s, the *Lillooet* data suggested a secular increase in $pCO_2$ in the equatorial Pacific Ocean of about 1 part per million per year. The monitoring effort will be intensified to observe the possible effect of an impending El Nino on the upwelling supply of $CO_2$-rich waters at the equator and their associated high $pCO_2$. The Station P observations of $pCO_2$ and other $CO_2$ parameters were conducted with the participation of Mr. Zheng Jiancheng, a visiting scientist from the Third Oceanographic Institute in Xiamen, P.R. China. *(Contact: C.S. Wong.)*

Work on $CO_2$ modelling was done on both the atmospheric $CO_2$ and on the oceanic process of the "biological pump". The amplitudes of seasonal changes of atmospheric $CO_2$ at the Canadian WMO Stations at Ocean Station P, Sable Island and Alert were examined for evidence of biospheric uptake of $CO_2$. A "biological pump" model was constructed using Station P time-series and sediment trap data to examine the process of photosynthetic uptake of $CO_2$ by phytoplankton and the subsequent transfer of carbon between the upper and deep ocean by the sinking of both calcareous carbon (shells and bones) and organic carbon

(fecal pellets of salp and copepods) detritus. *(Contact: C.S. Wong.)*

## Ocean Flux

Ocean Chemistry Division continued its extensive program on ocean flux of material in the N.E. Pacific Ocean to understand the biogeochemical cycle. Experiments were carried out, using moored sequential sediment traps in co-operation with Woods Hole Oceanographic Institution (for the third successive year) and also using free-floating systems as an in-house study. The cooperative IOS/Woods Hole project has yielded a valuable time-series of material flux data from 1000 m and 3800 m depths at Ocean Station P from September 1982 to the present. A peak occurred in 1982-83 with extraordinarily large quantities of material, mainly fecal pellets of salp and copepods, transferred from the surface to the deep ocean. Further time-series observations yielded relatively lower material inputs into the deep ocean, with quantities similar to other sediment trap studies. The 1982-83 peak amounted to 5-10 per cent of the historical productivity at Station P measured in the 1960s. To understand and to model the "biological pump", an additional program was initiated to fill in the knowledge gaps. The production of carbon in surface waters was measured to 100 m depth for seasonal C-14 uptake rates, using suspended bottle arrays, and the flux of material, including detritus carbon, carbonate and nutrient elments, was evaluated in the upper ocean between 0 and 1000 m using a string of free-floating sediment traps attached to a satellite-positioned ARGOS buoy. The free-floating traps were adrift for two to four days. The C-14 measurements, obtained by a metal-free method and other clean procedures, consistently yielded higher values by 50-100 per cent, than the historical data. Flux in the upper ocean, to 1000 m, was substantial, amounting to 10-20 per cent of the surface production. Because of decomposition of the detritus during *in situ* storage in the sediment traps for up to six months, experiments were conducted to quantify the oxidative loss of material.
*(Contact: C.S. Wong.)*

## Acid Rain

As part of the long-range plan to contribute to the Long-Range Transport of Atmospheric Pollutants Program (LRTAP) and to the future Global Tropospheric Chemistry Program (GTCP), a co-operative study was initiated with Atmospheric Environment Service. An acid-rain research laboratory was established; analyzing pH of rain waters over the ocean, anion and cation compositions of rain water, sulfur compounds in marine air and sea water, and aerosol compositions, including lead

isotopes. Shipboard collection facilities for rain and aerosols were also set up in cooperation with the University of Rhode Island and the SEAREX program. *(Contact: C.S. Wong, G. McBean.)*

## Chemical Tracers of Water Masses

In addition to lead and lead isotopic ratios as tracers of water masses, other studies were done, using tritium at Ocean Station P in cooperation with University of Miami and the Ocean Physics Division of IOS, and using freon-11 and freon-12 in cooperation with University of Victoria. The time-series of tritium since 1974 was examined with GEOSECS spatial maps pointing to the possible control of the vertical distribution of tritium by advection along isopycnals. *(Contact: A.E. Gargett, C.S. Wong, G. Ostlund.)*

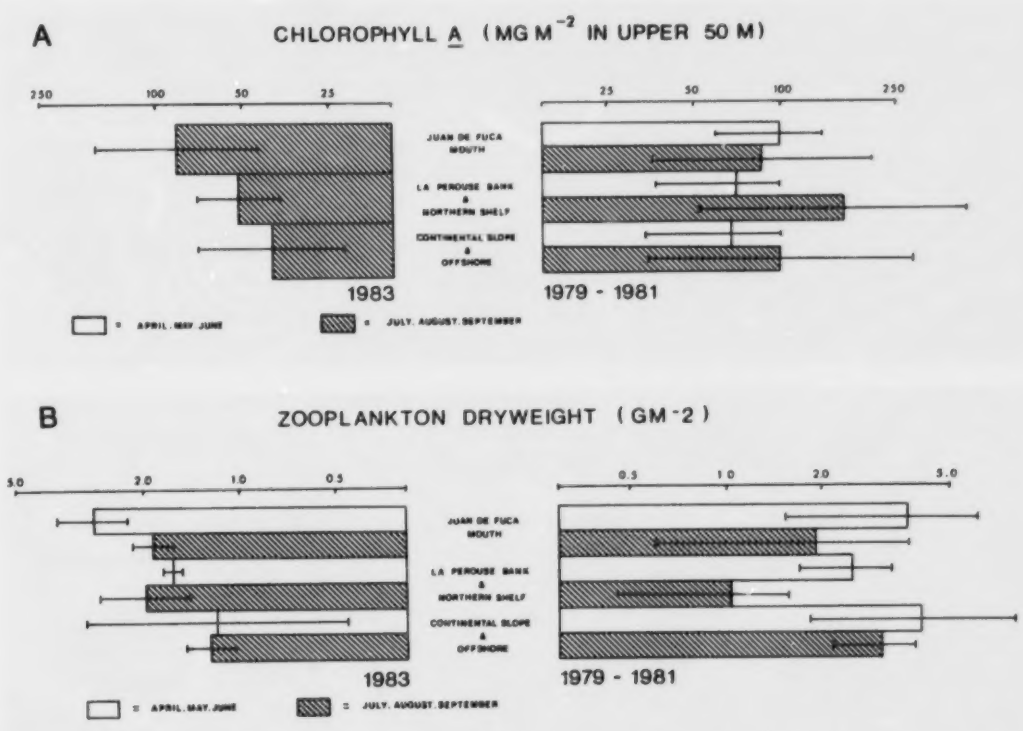
A contaminant-free freon method was developed by a University of Victoria graduate student under supervision at IOS. An intercalibration was conducted on NOAA's *Discoverer* to compare the IOS techniques to those of the Pacific Marine Environmental Laboratory (PMEL), shown to be compatible on the NOAA February-March cruise from Seattle to Alaska. Freon profiles were obtained in April-May, August and October-November on IOS cruises, and showed that freons, through air-sea exchange, had penetrated the upper ocean in subarctic waters to about 400 m depth. *(Contact: C.S. Wong.)*

# Ocean Ecology

### Plankton

In 1985 the plankton group within Ocean Ecology concentrated its field effort on the continental shelf region adjacent to southwestern Vancouver Island. The impetus was the initiation of a long term cooperative project with the Pacific Biological Station, focussing on the herring and demersal fisheries on or near La Perouse Bank, offshore from Barkley Sound. The goals were to establish the links from physical processes through the planktonic food chain to the commercial fish stocks, and to resolve and understand interannual variabilities at these levels of the marine ecosystem.

The changes in plankton population occurring at a fixed location are the combined result of growth and mortality of the local population plus advective and migratory exchanges with surrounding populations. Previous observations show that peak zooplankton abundance on the southern Vancouver Island continental shelf typically occurs in early summer. The species composition changes, and total biomass declines, later in the summer, despite high concentrations of phytoplankton which are food for the herbivorous zooplankton. In June and July, 1985, the importance of advective removal of zooplankton from the continental shelf region was examined by tracing upper layer populations using drogued drifter buoys with internal LORAN positioning electronics.




*A and B. Spring and summer seasonal average plankton biomass in three subregions of the Vancouver Island outer coast. Phytoplankton biomass (measured as chlorophyll concentration) is shown in top panel, zooplankton biomass (dryweight) in bottom panel. In normal years (1979–81), phytoplankton biomass is higher in the summer upwelling season (July–September) than in the spring (April–June), but summer zooplankton biomass is lower in the spring. In the summer following the 1982–83 El Nino, phytoplankton biomass was lower over most of the outer coast, but summer zooplankton biomass was reduced only in the offshore region.*

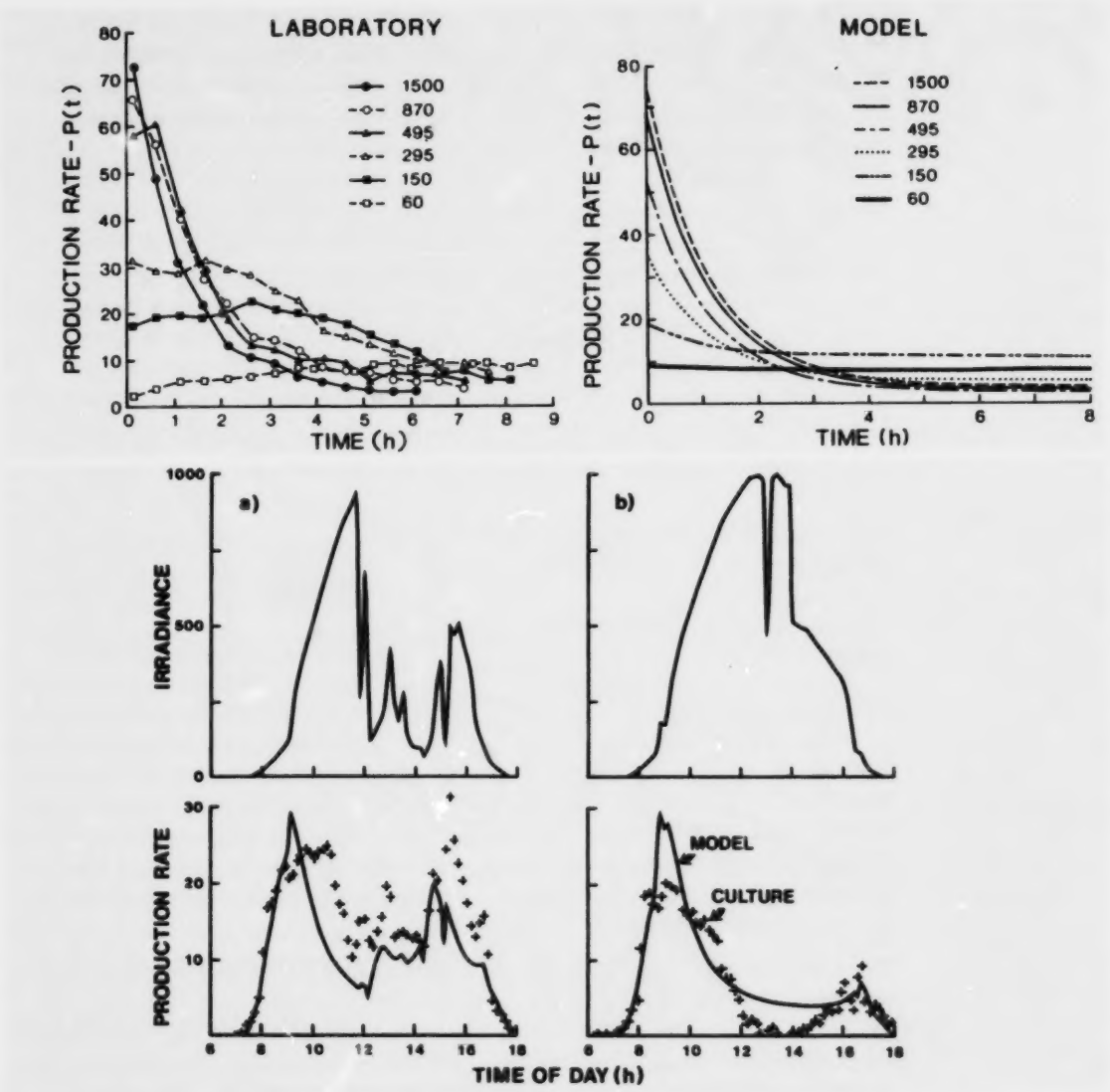
Drogues placed at midshelf moved seaward to the outer edge of the shelf and then south-southeast toward the Washington State coast. Average residence time on the B.C. shelf was only a few days. Replacement for the water advected seaward appears to be a mixture of deep upwelled water plus discharge from Juan de Fuca Strait. Both of these sources provide high concentrations of dissolved nutrients for phytoplankton growth, but tend to have low concentrations of the zooplankton species that form the normal spring population on the shelf. The advective flushing of the shelf (which appears to have been reduced in the El Nino year 1983) thus drives two competing processes: exporting biomass from the system, while enhancing the potential productivity of the organisms remaining. *(Contact: D. Mackas.)*

Field and laboratory experiments to resolve the spatial and temporal variablility of dai'y cycles in phytoplankton productivity were continued. This work will be concluded in 1986. If the cycles are sufficiently predictable, the results will allow a re-analysis of previous spatial data to produce synoptic maps of productivity variables in British Columbia coastal waters.

An unusually large "red tide", extending from the mouth of Barkley Sound to south of the entrance to the Strait of Juan de Fuca, was encountered during a cruise in July. The opportunity was taken to map the distribution of biological and other water properties throughout the area, using a combination of underway sampling and vertical profiling equipment. Fortuituously, similar measurements had been made in the area two weeks previously. Data will be analyzed to understand the preconditions that stimulate such a phytoplankton bloom.

Measurements of phytoplankton biomass and productivity, dissolved nutrients, and other water properties were made in Dixon Entrance and off the west coast of the Queen Charlotte Islands. These measurements will form baseline marine environmental data for the region, as little work of this type has been done here previously. The data will be useful for estimating fluxes into and out of Hecate Strait, which is of particular interest for its fish resources. *(Contact: R. Forbes.)*

Phytoplankton in the upper ocean experience short-term variations in light intensity for two reasons. First, changes in cloud cover and the daily cycle itself cause light variations, and second, various water motions move the plant cells vertically, in and out of the higher light levels near the sea surface. Many experiments have shown that the phytoplankton adapt or modify their photosynthetic capability physiologically in response to the light levels they have recently experienced. A model to




*Model predictions for laboratory data obtained by Dr. John Marra of Columbia University. The upper diagrams (A) show constant irradiance at a variety of light intensities after the cells were conditioned in the dark for 12 hours. Figure B reflects two different days in a culture of phytoplankton grown under natural sunlight in a rooftop greenhouse. Also, for typical response times of 1–2 hours, the model predicts that vertical displacements caused by internal waves are too rapid to allow significant photoadaptation to occur except at the semidiurnal and diurnal tidal periods.*

predict this time-dependent photoadaptation of phytoplankton to varying light levels has recently been completed. The model, based on linear response theory developed in power spectrum analysis, calculates the instantaneous rate of photosynthetic production based on a weighted integral of the light levels recently experienced by the phytoplankton cells. *(Contact: K. Denman.)*

## Benthos

The major new initiative this year was the joint undertaking with the groundfish biology group of the Pacific Biological Station to study Hecate Strait. Four areas were intensively sampled on three occasions during the year, on joint cruises. The benthic data will not only contribute the information needed by fisheries scientists to compare with data derived from fish stomach analyses, but will also provide a detailed account of seasonal changes of the relative abundance of species and changes in biomass.

This study took precedence over the study of recolonization of mine tailings in Alice Arm, which was also delayed owing to cancellation of a joint cuise in the fall of 1985. Samples are being obtained by Amax of Canada Limited and there is some prospect of reactivating the work in 1986.

The study of samples from Boundary Bay, stimulated by the suggestion of a connection between a PCB spill in a tributary stream and an apparent increase in mortality of grey whales, progressed to the point of identification of the samples to major groups. These show a diverse fauna at nearly all stations sampled and no basis for immediate concern. The detailed identification of species is now being pursued so as to provide a quantitative description of the macrobenthos of an area quite susceptible to environmental impact.

The study of the benthos of the continental shelf is slowly reaching the reporting stage. The bulk of the species identifications and verifications has been completed, and all the primary tables corrected and condensed for publication. It seems as though differences in substrate have sufficient impact on the fauna that the influence of other variables will be difficult to discern despite attempts to minimize the variability of substrates sampled. *(Contact: R.O. Brinkhurst.)*

Taxonomic studies on oligochaetes were continued, and as usual a considerable amount of support was provided on a worldwide basis to applied biologists who supplied material for identification or verification,

solicited information and advice, or sent manuscripts for review. A second trip to Lake Titicaca and the Amazon River in Peru was most successful in that this time some of the most significant but poorly described South American species were re-discovered. A detailed account of South American species will result. A new identification manual for industry and government biologists in North America was completed and published. The two-part review of the complex estuarine genus *Tubificoides* was published. Courses in identification were run for the Tennessee Valley Authority, Carolina Power and Light and the British Estuarine group. A revision of evolutionary and comparative methods in systematics was completed and is now in the review process. An experimental study supported the hypothesis that hair setae can be reduced or absent in specimens obtained from areas of high conductivity in the water, or at the inner end of estuaries. *(Contact: R.O. Brinkhurst.)*

Two post-doctoral fellows, A.F. Nemec and S.K. Juniper, completed their terms with us and were replaced by Y. Simard and (via the University of Victoria) K. Wong.

## Numerical Taxonomy

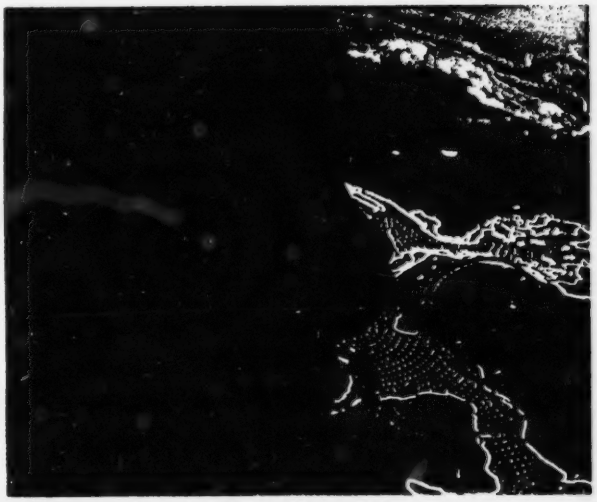
A number of different numerical techniques, including cluster analysis, character compatibility analysis, and the method of parsimony, were used to investigate the evolutionary relationships that exist among 23 species of the oligochaete family, Naididae. The classification of the Naididae was then reviewed and a revised classification, based on the results of the analyses, was proposed. In addition, the relative performance of the numerical methods was assessed subjectively and according to several objective criteria. The conclusions drawn from this and similar studies not only enhance our understanding of evolutionary processes, but also lead to greater proficiency in organizing and interpreting what are often very large data sets. *(Contact: A.F.L. Nemec.)*

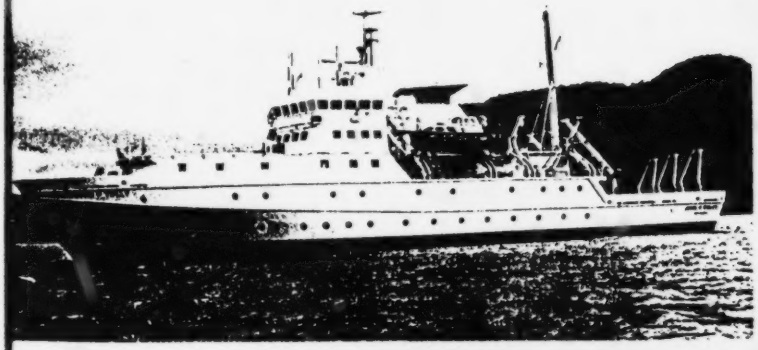
## Time Series Analysis

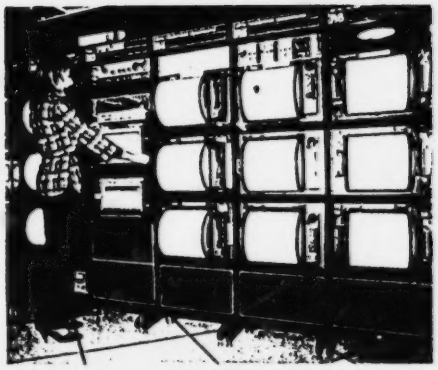
Time series analysis has many applications in oceanography, as well as other fields as diverse as astronomy, economics and medicine. One example of an oceanographic application is the analysis of temperature measurements of a hot vent, which is currently underway (with Kim Juniper). The outcome of this analysis should provide useful information regarding the physical conditions to which the biological communities of hot vents are subjected. *(Contact: A.F.L. Nemec.)*

The search for periodicities is an important aspect of time series analysis, since periods (wavelengths, in the case of spatial data) often have significant physical interpretations. The analysis of observations that are not uniformly spaced presents special problems. Although there are a number of ad hoc techniques ("phase dispersion minimization methods") that are used to estimate periods when the data are unequally spaced, little is known about the statistical properties of these methods. In particular, there is no objective way of assessing the statistical significance of period estimates. In response to this limitation, a randomization test was developed. *(Contact: A.F.L. Nemec.)*

# Ocean Information







# Ocean Information

The Ocean Information Division provides information about IOS programs to specialized clients, the media and the general public; it also oversees a program to provide a long-term record of coastal sea surface properties in B.C. The information given out must match the needs and capabilities of the recipient, and the Division's products consequently vary from general letters and brochures about oceanography or hydrography to quite technical publications and advice.

The demand for data by clients outside the oceanographic community appears to be increasing. Prominent among the groups requesting information is the growing aquaculture industry on the west coast, for which information about the temperature, salinity, nutrients and circulation is an important factor in deciding where to locate.

Among the Division's specialized clients are the regulatory and advisory bodies concerned with protecting marine environmental quality. In 1985, we closed the book on our involvement with the federal environmental Panel for hydrocarbon development in the Beaufort Sea and opened a new one for hydrocarbon exploration off the West Coast. The IOS contribution to the federal-provincial Panel hearings into proposed drilling in Hecate Strait, Dixon Entrance and Queen Charlotte Sound was one of the most demanding of our advisory tasks during the year.

# Climatology

The B.C. Shorestation Oceanographic Program obtained daily surface (one-metre depth) seawater salinity and/or temperature measurements at 16 locations in 1985. In addition, the 1984 data were published.

Preliminary examination of the 1985 data suggests that the values of surface salinity recorded at each site exhibited no significant departure from long-term values. The same characteristics appeared to describe the corresponding temperatures for the first 10 months of the year. However, during November and December, there was an abrupt lessening of temperature along the coast generally. The cooling was basically defined by anomalies greater than about 1.5 standard deviations from the long-term monthly means for the seven stations with 45 or more years of data.

The changes in anomaly were abrupt both with time and in magnitude. Anomalies of between 1.5 and 2 standard deviations occurred at all "open-ocean" stations (e.g. Langara Island and Amphitrite Point) for one or both of these months. By far the largest anomalies—more than three standard deviations—were recorded in the Race Rocks area, a somewhat more sheltered location than the open-ocean sites. They were the greatest ever recorded at this location. Surface waters of the Strait of Georgia—the area most protected from "outside" marine influence—were also markedly colder, as indicated by the anomaly of almost two standard deviations registered at Entrance Island, the only long-term station reporting in the Strait in 1985. The presence of this effect tended to be borne out by other, shorter-term, records obtained in the Strait. Among the coldest seawater temperatures ever recorded in the program were those found at the beginning of December at the West Vancouver site (1.5 to 1.9°C). For comparison, it may be noted that positive "warming" anomalies of between two and three standard deviations were fairly common at the outside coast during the major El Nino event in 1982-83. The markedly cooler surface waters of late 1985 were presumably an oceanographic manifestation of the extremely severe weather conditions on the B.C. coast during November and December. *(Contact: L.F. Giovando.)*

# Environmental Advisory Services

During 1985, Ocean Information Division coordinated the oceanographic component of DFO's involvement in the West Coast Offshore Exploration and Environmental Assessment Panel. The Division's work comprised several tasks, including: the provision, to the federal-provincial Panel, of a large amount of information required during the course of the hearings; attendance (with other Institute personnel) at major public hearings at Prince Rupert, Vancouver and Victoria in October; and contribution to the submission dealing with DFO's position and recommendations on the proposed exploration for hydrocarbons. Release of the Panel's report is expected in early 1986. *(Contact: L.F. Giovando.)*

The Division continued to be the focus of the Institute's support to two (Pacific and western Arctic) regional ocean dumping advisory committees (RODAC). Contributions were tendered toward the approval of about 50 applications and to several formal reviews. The most difficult subject

dealt with during the year comprised two applications for the disposal of substandard or waste gypsum wallboard.

Participation on the Arctic Waters Advisory Committee (AWAC) required the provision of oceanographic advice and information on diverse issues of safety and environmental protection arising from applications by offshore industries. Although offshore activity in the oil and gas sector appears to be scaling down somewhat in Canadian waters, 1985 was relatively busy in the Beaufort Sea and Sverdrup Basin regions. For example, drilling approvals for Gulf, Esso, Dome, Chevron and Panarctic necessitated the governments' setting of environmental operating conditions, including physical and environmental monitoring programs, for about 20 wells. In addition, 10 dredging leases and applications for island and harbour construction were reviewed for their technical and environmental soundness. *(Contact: B.D. Smiley.)*

IOS contributed to a major industry-government effort to formulate a code of practice for the future use of oil-based muds in Arctic waters. Oil-based muds are preferred in some applications to prevent the rotating drill pipe from sticking. However, their use poses an increased environmental risk to marine life when discharged into the ocean.

Several companies improved and updated their oilspill contingency plans during the year. One such plan was suddenly tested on September 17 when about 450 tonnes of diesel oil was released into the Beaufort Sea, 10 km off the mouth of the Mackenzie River delta. The spill occurred when the Esso Resources artificial island, made of sand and gravel, was damaged extensively during the worst summer storm recorded in the region. With winds of 50-55 knots, and estimated four-metre waves breaking on the beach, about one-half the island's working surface eroded into the sea, taking with it the drill rig, a three-storey modular camp and one of four diesel storage tanks. The resulting diesel oil slick floated for about three days before dispersing. Throughout the spill event, IOS scientists provided oceanographic advice to the Canadian Oil and Gas Lands Administration (COGLA) in Yellowknife on the fate and behaviour of oilspills on the ocean surface. *(Contact: R.C.H. Wilson.)*

# Information Management

For several years, the Division has produced a series of inventory reports to facilitate access to oceanographic data in the Arctic. In 1985, the first

steps were taken to make this now substantial body of data available to external users by means of a computer on an interactive database. When it is offered to users in 1986, this service will greatly facilitate the search for accumulated physical, chemical and biological data of the western Arctic.

Called the Arctic Data Cataloguing and Appraisal Program (ADCAP), detailed information about collection techniques and procedures, storage and analysis, together with measurement quality ratings and data services, allow users to gain an impression of the completeness, reliability and accessibility of these data.

To date, seven inventories, averaging 300 pages, of historical overviews, tables, station maps, location indexes, references and sources have been published. In 1985, contractual work on several new catalogues continued, e.g. Beaufort Sea whales, zoobenthos and fishes, and Northwest Passage fishes and zoobenthos; and four more—Beaufort Sea whales, Beaufort Sea plankton, Northwest Passage whales, and Queen Elizabeth Islands chemistry—were started.

An opinion poll to assess the effectiveness of ADCAP, conducted in 1985, indicated that the majority considered the catalogues quite useful as reference tools (to varying degrees) for wide ranging purposes, from research planning to engineering design or impact assessment. *(Contact: B.D. Smiley.)*

An initiative analogous to ADCAP—the West Coast Data Inventory and Appraisal Program—has been commenced for the Pacific Ocean off Canada. For convenience, and also by analogy, the program title has been designated as WESCAP. To date, two inventories—both dealing with physics—have been published: that for Dixon Entrance-Hecate Strait-Queen Charlotte Sound, and that for offshore waters out to the Canadian 200-mile fishing limit. Corresponding inventories for chemistry are nearing completion. The emphasis that has been initially placed on waters north of Vancouver Island has resulted from requirements perceived as ensuing from the proposal to explore for hydrocarbon in these waters.

For purposes of regional planning, impact assessment, research investigations and regulatory guidance, a complete record of some major Arctic industrial activities associated with the oil and gas sector is also being compiled. The first volume describes the more than 100 marine dredging operations that took place in the Beaufort Sea from 1959 to 1982. The second volume covers offshore seismic surveys in the Sverdrup Basin area from 1974 to 1984. A third publication, dealing with drill waste

discharges, is in preparation. *(Contact: B.D. Smiley.)*

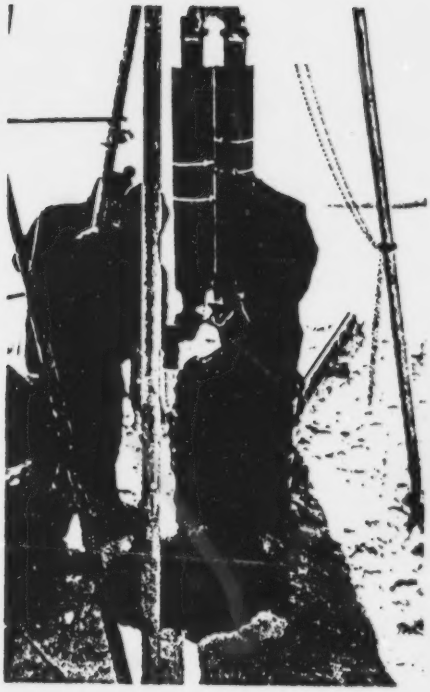
# Public Information

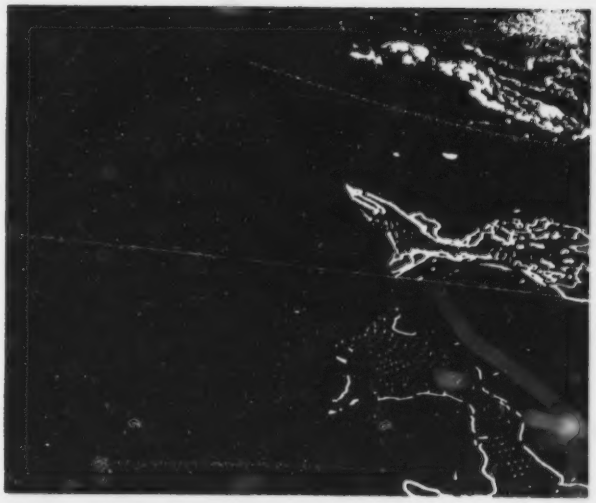
The Division sponsored a project, under the auspices of International Youth Year, to improve the resource material for the public tour program at IOS. A group of young professionals designed and produced a number of static displays and completely revamped the Institute's multi-image slide show.

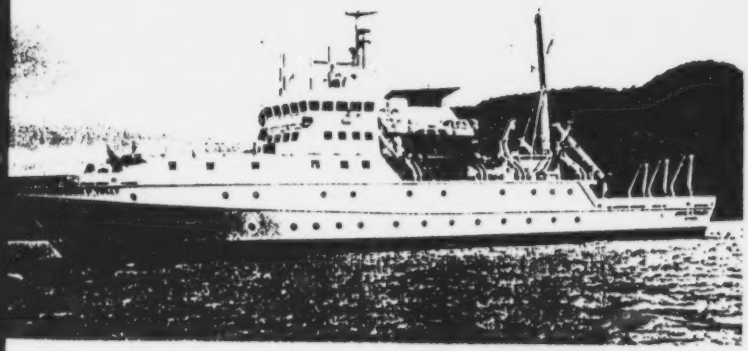
The fourth in the new series of IOS Annual Reviews was prepared as were contributions to other government and non-government publications. The IOS Report, produced monthly, was continued and distribution increased to include various client and user groups.

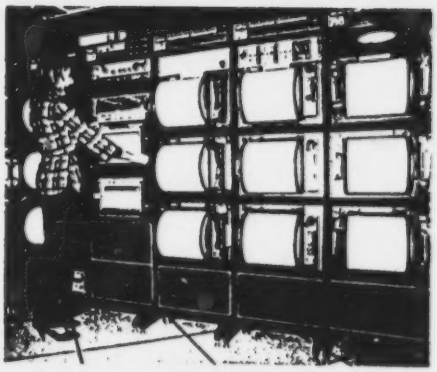
Advice and materials were provided to the Pacific National Exhibition for the feature exhibit—Hidden Faces of the Sea—at the 1985 fair. An estimated 1.2 million visitors, the second highest in history, attended. *(Contact: K. Glover.)*

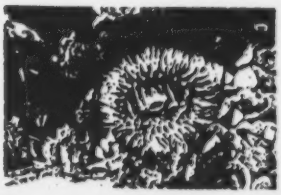
# Ships











# Ships

Ship Division continued to provide ship, launch, submersible and workshop support for the scientific and hydrographic programs of the Institute of Ocean Sciences (IOS), the Pacific Geoscience Centre (PGC), universities and other federal agencies in 1985.

Of major importance was the official acceptance of the CSS *John P. Tully* in the early summer. After commissioning, the ship commenced service in the western Arctic.

The year also saw the charter vessel MV *Pandora II* and the submersible *Pisces IV* working out of the Bedford Institute of Oceanography on the Atlantic coast.

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CSS *JOHN P. TULLY* (69 m overall; gross tonnage 2199)
*Master:* B.L. Newton *Chief Engineer:* P. Pereira

After delivery from Bel-Aire Shipyard Ltd. on June 4, a month was spent by the captain and crew familiarizing themselves with the new ship. A commissioning ceremony was held on June 22 at the Institute of Ocean Sciences.

On July 10, the CSS *John P. Tully* departed for the Beaufort Sea for hydrographic survey of the Herschel Island and Kugmallit Bay areas, and a geophysical survey, conducted by Energy, Mines and Resources, between Herschel Island and the international boundary. The ship arrived back at IOS in early October.

During October and November, the CSS *John P. Tully* was used off the B.C. and Washington coasts by all three IOS oceanographic divisions.

In December, the ship was returned to the shipyard for routine warranty work, which, despite the heavy ice conditions encountered on her maiden voyage, was not serious.

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CSS *PARIZEAU* (64.6 m overall; gross tonnage 1314)
*Master:* A.G. Chamberlain *Chief Engineer:* G. Winterburn

The CSS *Parizeau* provided support for the Pacific Geoscience Centre, the Department of National Defence (DND) and Canadian universities in

addition to working with Ocean Physics Division, Tidal and Current Surveys and Ocean Chemistry Division. As has become customary, the CSS *Parizeau* acted as a Search and Rescue vessel for the herring roe fleet.

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CSS *VECTOR* (39.6 m overall; gross tonnage 516)
*Master:* R.W. MacKenzie *Chief Engineer:* R. Pearson

Support was provided by the *Vector* to programs for Ocean Physics Division, Ocean Chemistry Division, University of British Columbia, Simon Fraser University, Tidal and Current Surveys, Environmental Protection Service and Pacific Geoscience Centre. A two-week cruise was also undertaken for Royal Roads Military College.

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CSS *RICHARDSON* (19.8 m overall; gross tonnage 59)
*Master:* J. LeGarff

Most of the season was spent supporting the Hydrographic Division conducting surveys in the Queen Charlotte Islands area. The *Richardson* was also used as a Search and Rescue vessel during the 1985 herring roe fishery.

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MV *PANDORA II*, on charter (58.2 m overall; gross tonnage 1378)
*Master:* S. Gulati *Chief Engineer:* R. Rogers

The *Pandora II* was employed for most of the 1985 field season on the Atlantic coast, acting as the mothership for the *Pisces IV* submersible and providing support for scientific activities being carried out by the staff of the Bedford Institute of Oceanography and the Atlantic Geoscience Centre.

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*PISCES IV* (6.1 m overall; gross tonnage 12)
*Chief Pilot:* F. Chambers

In preparation for east coast deployment, *Pisces* underwent an extensive maintenance period. The submersible completed a two-week operation off the west coast for DND in conjunction with the U.S. Navy, then headed east onboard *Pandora II*. While based on Canada's east coast in 1985, *Pisces IV* was utilized by Bedford Institute and Atlantic Geoscience

Centre scientists to conduct 14 major cruises, some above 70° north. The two most significant operations were the discovery of natural oil seeps off Scott Inlet and the recovery of two current meters lost in 1983 due to release failures. *Pisces IV* returned to IOS on December 4 onboard the MV *Pandora II*.

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*BARGE PENDER*

During 1985, the barge was mainly used by the Hydrographic Division. In April and May, surveys were conducted in the False Creek area of Vancouver, in connection with Expo 86. From June through September, the *Pender* operated in the Tofino area. Ocean Physics Division used the barge in local waters during November for echometer experiments.

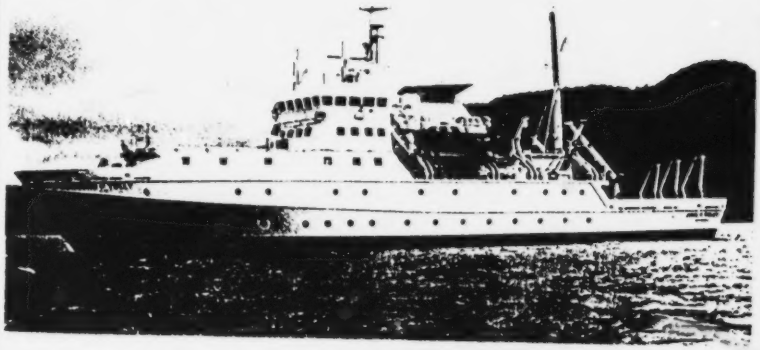
## Institute Workshops

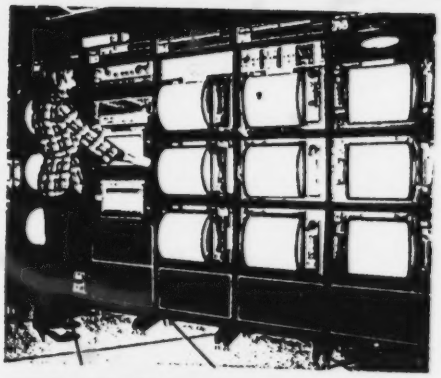
The depot staff were responsible for construction, repair and maintenance of the Institute's fleet of launches and small boats, as well as providing mechanical support for the *Pender*, CSS *John P. Tully* and CSS *Richardson*. Workshop staff also rebuilt the three diesel engines on the CSS *Vector* and one other diesel motor. Over 400 work orders were completed for various IOS divisions.

## Deck Machinery

Staff continued to maintain and service winches and associated equipment in use on the IOS fleet. During 1985 considerable effort went into fitting winches, etc. to the new CSS *John P. Tully*.

# Management Services





# Management Services

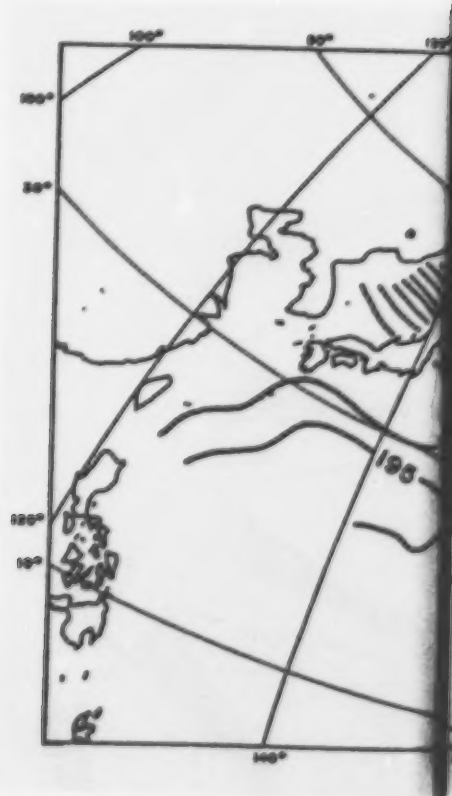
With the commissioning of the CSS *John P. Tully* in 1985, the overall workload in Management Services has increased by approximately 10%. This increase was absorbed through productivity, the use of several term positions and temporary help agencies. Very little progress has yet been made in the development of a departmental central financial system, which still leaves IOS line managers relying on an out-dated system for financial information.

One job development program (FRED) came to an end in 1985 and another began. DFO is jointly administering $15 million worth (85-86) of job development programs with Employment and Immigration Canada (EIC). At IOS, 14 projects creating 78 jobs and with a total value of $1.39 million currently have been approved by EIC. The intent of this program is to provide training and work experience primarily in the private-sector marine science and technology industries.

Several significant projects were undertaken by Management Services in 1985. Among these were: the purchase and installation of an uninterruptable power supply for automated cartography; essential repairs to the IOS wharf; and, modifications to offices and labs. In addition, Management Services personnel participated in the development and presentation of training materials in the areas of purchasing and finance, as part of a middle management orientation course.

# DEPARTMENT OF ENVIRONMENT

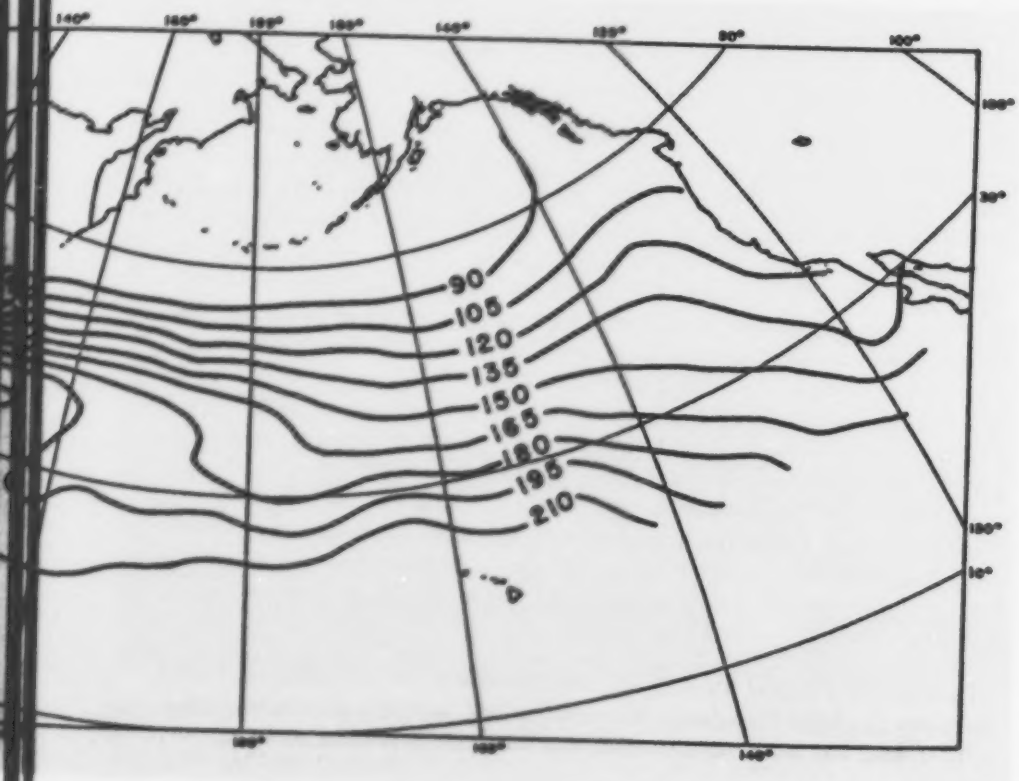
*The 30-year average of the total amount of heat transferred from the ocean to the atmosphere over the North Pacific Ocean. (Units are watts per square metre.) Notice the maximum heat transfer just east of Japan over the Kuroshio Current system.*



# Atmospheric Environment Service — Canadian Climate Centre

## Atmosphere-Ocean Interactions

The heat transferred from the ocean to the atmosphere plays a major role in determining the evolution of the atmospheric climate. The atmosphere has a relatively short memory (days to weeks) so it is unlikely that predictions of seasonal or longer period climate changes can be based on atmospheric information alone. On the other hand, the oceans have a relatively long memory time (ranging from months to decades) depending on the depth of the ocean considered, and it is hoped that this information will enable much longer climate predictions. During the past year the variability of the total amount of heat transferred from the

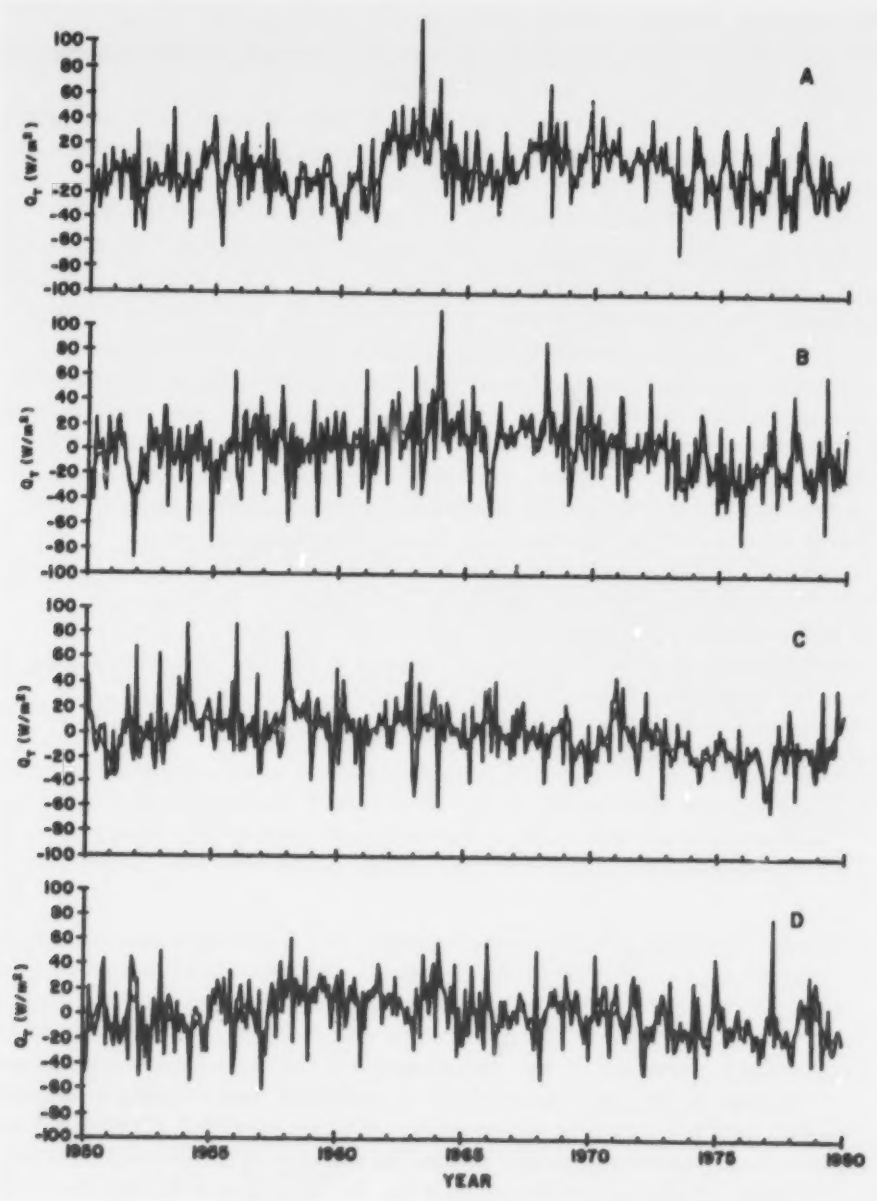


ocean to the atmosphere over the north Pacific Ocean has been investigated. This work is being done in cooperation with Y.P. Zhao, a visiting scientist from the Institute of Oceanography, Academia Sinica, China.

It was first found that the annual cycle of total ocean to atmosphere heat transfer varied in different regions of the ocean. On the west side of the ocean, the Asian monsoonal circulation played a major role while, to the east, the variations of storminess, and the annual cycle of sea surface temperature, dominated. The variations from this annual cycle—the interannual variations—also differed across the ocean basin. The heat transfers were spatially correlated over the Kuroshio current system, but not with the heat transfers over the eastern two-thirds of the basin. From the Alaska and California current areas heat transfers were highly correlated. In the winter time there is a tendency for the anomalies of heat transfer to be of opposite signs over the eastern and western sides of the ocean. Looking at the basin as a whole, the anomalies of heat transfer since 1973 have generally been negative while in the 1960 s they were generally positive. In 1962-63 there was a marked positive anomaly over the western part of the basin. It is important to understand the reasons for these major anomalies as they present the possibility of a basis for future prediction techniques.

The relationship between the ocean-to-atmosphere heat transfer anomalies and the anomalies of the atmospheric circulation, as represented by the sea level pressure and 700mb height fields, was then investigated. As expected, the anomalies in the heat transfer had a large local impact in the winter. Greater amounts of heat from the ocean were related to a deeper Aleutian low pressure system which also tended to move to the southwest. The pressures both immediately upstream and downstream of the Kuroshio area were also affected. In the summer, there was no significant local correlation, but there was an interesting correlation between heating over the mid-Pacific Ocean and the 700mb height anomalies over the Tibetan Plateau. This can be explained in terms of a zonal-vertical circulation pattern that is established downstream of the Plateau, which typically has a 700mb pressure as its surface pressure. It appears that the explanation for both these phenomena is one of the atmosphere affecting the ocean-to-atmosphere heat transfer, rather than the other way around. This will be investigated further.

Of particular interest for climate prediction are the correlations found between the heat transfer to the atmosphere over the Kuroshio in the winter, and the sea level pressure patterns the following summer over




*Time series of the anomalies of total heat transfer from four characteristic areas of the North Pacific Ocean: A) the Kuroshio; B) the central North Pacific; C) the Gulf of Alaska; and, D) the California Current.*

eastern North America and the following winter over Europe. A mechanism to explain these correlations is being sought. Some cooperative modelling work being done by L. Mysak and his students will help in this regard. *(Contact: G.A. McBean.)*

## Intercomparisons of Atmospheric Sounding Systems

Two studies have been completed, in cooperation with D.J. Phillips and J.R. Mathieson of AES, Pacific Region, to compare atmospheric sounding systems. During the Storm Transfer and Response Experiment (STREX), upper-air balloons were tracked by radar on the Weather Ship and by navigation signals (Navaid). The winds deduced from these systems were found to compare well with a small bias but having a larger root-mean-square (RMS) difference (1.7m/s). These differences are acceptable for operational purposes. In a second study upper-air soundings were made at Port Hardy and an intercomparison of wind, temperature and humidity measurements was carried out. The temperature measurements agreed, on average, to within 0.3°C with an RMS of about 1°C. There were larger and significant differences in the humidity measurements. These differences reflect the differences between two types of radiosondes. The wind differences between the Navaid system and the radio theodolite tracking were, in the mean, about the same as the radar-Navaid differences, but the RMSs were about twice as large. *(Contact: G.A. McBean.)*

# Canadian Wildlife Service

During the year, three studies of water birds were completed by CWS. One compared the selection of habitat by nesting Mew Gulls of Vancouver Island lakes to that of the Glaucous-winged gulls nesting in the Gulf Islands. Another compared the nesting biology of Mew Gulls on Vancouver Island with that of the species in Scandinavia and the U.S.S.R. The third examined the nesting habits and habitat of Ancient Murrelets and Cassin's Auklets in the Queen Charlotte Islands.

The purpose of the Mew Gull studies was to determine nesting populations and the types of lakes and islands on Vancouver Island selected for nesting purposes. The intent of the Ancient Murrelet and Cassin's Auklet study was to determine why the Queen Charlotte Islands has the largest nesting population of Ancient Murrelets and the second largest of Cassin's Auklets in the world. *(Contact: Kees Vermeer.)*

A major project (started in 1985) by the Canadian Wildlife Service (CWS) at the Institute of Ocean Sciences was a study of the population dynamics of the Glaucous-winged Gull in the Strait of Georgia. This is the only gull species that nests in the marine habitat of British Columbia. Although it is numerous, and rapidly expanding, it nevertheless makes up only two percent of the nesting seabird population in British Columbia. More numerous are the several species of alcids, such as the Ancient Murrelets, Cassin's Auklets, Rhinoceros Auklets, and Fork-tailed and Leach's Storm-Petrels. These birds are less frequently seen by public than are gulls because they chiefly breed on the outer west coast; they are nocturnal, visit colonies at night, and nest in burrows dug into the soil.

The Glaucous-winged Gull has increased steadily since the 1920s. Before then it was not very numerous on our coast; however, urbanization in southern British Columbia has led to an increase in human refuse upon which the gulls feed, particularly during the winter season. The prevailing theory is that the gull population before the 1920s was limited because of heavy winter mortality. In the winter, the gulls' access to intertidal foods is limited since low tides occur at night and they are not nocturnal foragers. The increase of human refuse in garbage dumps and offal from fishing activities may have reduced the gulls' winter mortality over the past several decades. Another reason for the increase in gull numbers in recent years may be that "egging" of nesting colonies has gone out of fashion. In contrast, at the beginning of this century egging

was carried out at such an alarming rate that guards were posted at some nesting islands to protect the colonies from this activity.

The first major survey of the Glaucous-winged Gull nesting population in the Strait of Georgia was conducted in 1959-1960; a second one took place in 1974-1975. It was found that the gull population had increased greatly between 1960 and 1975. A third survey of the nesting population is planned in 1986 to determine if this increase is continuing. Results of a preliminary survey of colonies in the Gulf Islands in 1985 indicated that such may actually be the case, as increases in gull numbers, as well as in nesting colonies, are found to have occurred. During the last few decades Glaucous-winged Gulls have also invaded the cities and are now nesting in the hundreds on the roofs of buildings along Burrard Inlet and False Creek in Vancouver. An over-abundance of these gulls could result in human health hazards, safety hazards near airports, and displacement of other bird species. It is for these reasons that the present population growth curve will be examined. If the gull population continues to grow, measures may have to be taken to control the nesting population. *(Contact: Kees Vermeer.)*

# DEPARTMENT OF ENERGY, MINES AND RESOURCES

## Pacific Geoscience Centre

# Earth Physics Branch and Geological Survey of Canada

## Director's Foreword

The Pacific Geoscience Centre (PGC) had a very productive year in 1985. A number of important short term national and western Canadian geoscience needs were met and there have been many exciting new achievements in fundamental geoscience. Some of the highlights:

The Offshore Boundaries Program that is to end in March 1986 provided funds for extensive studies on the Juan de Fuca Ridge as well as along the continental margin. It permitted compilation of a comprehensive geoscience data base for the west coast and Beaufort Sea offshore that is not only essential for boundary negotiations but that will be very valuable for many other uses. Along with the Frontier Geoscience Program it also provided funds for several contracted multichannel seismic lines across the Vancouver Island continental margin and a contracted extensive SeaMARC II acoustic imaging survey both on the Juan de Fuca Ridge system and along the edge of the continental shelf. The offshore seismic lines provided an extension of last year's Lithoprobe Vancouver Island lines.

A highlight of the Juan de Fuca Ridge work was the discovery and sampling of a "sediment-hosted" sulphide mineral deposit in a sediment pond near the north end of the Juan de Fuca Ridge proper. This type of deposit is potentially very large. On land such deposits are among the largest found and are of particular economic importance.

The Frontier Geoscience Program continued at a higher level its studies directed toward the petroleum potential along the western margin of Canada and in the northern Yukon-Beaufort Sea region. In addition to the seismic and acoustic imaging surveys, the Program allowed for a wide range of geoscience studies including an aeromagnetic survey of the Queen Charlotte area. Interest in petroleum exploration in the area has increased. A Panel responsible for recommending on what conditions exploration can continue has held public hearings and will report in the near future.

Increasing effort is being directed toward the International Ocean Drilling

Project (ODP) by PGC scientists. Participation onboard the ship *JOIDES Resolution* is planned for 1986-7, and surveys have commenced for holes to be drilled off the Canadian west coast in 1989-1990.

Two significant earthquakes of magnitudes near 7 occurred in the Nahanni area of southwestern Northwest Territories in October and December, the largest events in Canada for 15 years. The region has had relatively low previously recorded seismicity and these events may have an important impact on earthquake risk estimates for the region. Field parties from PGC did aftershock and other studies in the area following both events in spite of the remote location and the severe difficulties of working in the northern winter.

Important for the future of the Pacific Geoscience Centre was the announcement that as of April 1, 1986 the Earth Physics Branch is to be merged with the Geological Survey, and that PGC is to be merged into one division with the Cordilleran Geology Division of Vancouver. Although coupled with difficult but hopefully small reductions in resources, the reorganization will permit PGC to operate as one unified group. A time of change is always a time of uncertainty and concern, but I am confident that the future is bright.

The staff of the Pacific Geoscience Centre working together have created a geoscientific research establishment that is second to none, and of which we can all be extremely proud.

# Marine Sedimentology

## Estuarine and Marine Delta Sedimentation

As in previous years demand remained high for geological data from the Fraser River delta which can help formulate environmental/engineering guidelines. During 1985 results of geological research have been applied to a wide range of projects sponsored by other agencies including assessments of the physical/biological impact of the expansion of the Roberts Bank Coal Port, the design of an appropriate dyke for the Tsawwassen Indian Reserve marsh on Roberts Bank and creation of intertidal dredge spoil islands on which marsh habitats can be established.

Highlights of the summer's field activities include a trial survey of the

structure and lithology of the Fraser delta employing high resolution seismic reflection profiling, electrical resistivity surveying and coring. This program likely will be expanded into a major multidisciplinary research effort involving government, university and private sector personnel. The acquired geological data should enhance assessments of seismic risk for the area. Major milestones have been achieved in two delta-related theses studies supported by the Geological Survey of Canada at the Geography Department of Simon Fraser University. The results of one study provide, for the first time, direct evidence of a "proto-delta" below the surface of the eastern part of the present delta. The second study has identified the advantages of airborne multispectral mapping techniques over satellite systems for mapping local coastal environments. Field work performed jointly with the Department of Geography at the University of British Columbia in the outer reach of the main channel of the Fraser River established that suspended load increases with increasing river discharge and decreasing tidal elevation and that most sediment is transported in suspension rather than as bedload. The results of this study will be applied to assessments of the stability and sediment budget of the delta front. *(Contact: J.L. Luternauer, now at Geological Survey of Canada, Vancouver.)*

## Fiord Studies

Studies of underwater slope failures in British Columbia fiords are continuing in a number of areas. Following the catastrophic draining of an ice-dammed lake in 1984, South Bentinck Arm was surveyed using side scan sonar and seismic reflection to determine if any offshore failures occurred as a result of the rapid delivery of large quantities of sediment to the delta. Broad channels with large scale bedforms and incipient slope failures were found to be common on the lower parts of the delta and may be related to the flood.

Studies of long-distance sand transport through channels in Bute Inlet, in cooperation with Louisiana State University, continued with the installation of three moorings, consisting of tilt sensors, current meters and water bottles. Bottom-mounted acoustic transponders were installed in order to detect seabed movement during the one-year deployment period.

Debris torrents in creeks along the eastern shore of Howe Sound have resulted in considerable property damage and loss of life. To assist in planning protective structures in this area, the nearshore zone was surveyed using echosounding and side scan sonar. *(Contact: B. Bornhold.)*

## Continental Shelf Studies

Research continued on the character and genesis of submarine slope failures, coarse gravel beds, active sand wave fields and shallow subbottom gas accumulations in Queen Charlotte Sound. All of these factors are important for hydrocarbon exploration and development in this area of the continental shelf. The project has established that few if any major slope failures have occurred during the last 10,000 years. As part of this project the remanent magnetization is being measured on samples taken from radiocarbon dated sediment cores collected in Queen Charlotte Sound. This information should allow sedimentation rates to be established and the correlation of geological units and geological events in different areas of the sound. *(Contact: J.L. Luternauer, now at Geological Survey of Canada, Vancouver.)*

Mapping of the surficial geology and morphology continued off northwestern Graham Island including a contract survey. The survey, in water depths from 5 to 70m, involved precision echosounding, side scan sonar mapping and grab sampling. As with the area off central northern Graham Island completed in 1984, three 1:25,000 maps of bathymetry, morphology and sediment type have been produced. *(Contact: B. Bornhold.)*

## Juan de Fuca Ridge Sediment Studies

A one-month cruise was carried out to Middle Valley on the northern Juan de Fuca Ridge that included an investigation of the nature of sedimentation in an area of very high heat flow. Forty-two sediment cores were collected, many of which revealed evidence of hydrothermal input. One core obtained from an apparently hydrothermal mound structure consisted of over 2m of massive iron and zinc sulphides. Zinc values ranged from 2.7 to 4.6%. Other cores contained anomalous manganese and barium rich layers, pebble-size calcium carbonate nodules, and layers of coarse-grained, crystalline material, probably barite. *(Contact: B. Bornhold, E. Davis.)*

## Yellow River Delta, People's Republic of China

An international team from Canada, the United States and China carried out a reconnaissance study of sedimentation on the offshore areas of the present Yellow River (Huanghe) delta and adjacent Bohai Sea. The work involved multi-frequency echosounding, sub-bottom profiling, side scan

sonar traverses, coring, deployment and recovery of current meters and suspended matter sampling. Studies in the summer of 1986 will attempt to document the processes related to the dense turbid underflow during the main flood of the river. *(Contact: B. Bornhold.)*

## Sedimentology Laboratory

The sedimentology laboratory provided technical and analytical support for the following projects: estuarine and deltaic sedimentation, continental shelf sedimentation, fiord studies, continental shelf mapping, Juan de Fuca Ridge studies, and mud underflow dynamics. Samples from 80 cores, 625 grabs and two dredges were received from twelve field expeditions. Sixty cores were opened, lithologically described and subsampled; 625 grainsize analyses were completed; 270 subsamples were analysed for $CaCO_3$; 125 subsamples were prepared for micro faunal analyses; 15 shell samples were prepared and sent off for $C^{14}$ dating; 200 subsamples were prepared for paleomagnetic measurement. All of the samples and subsamples were archived.

The sediment lab operation was improved with the settling tube and sedigraph data being directly logged by a microcomputer and the data then being merged with gravel weights and field information. Data storage and retrieval, plus subsequent analysis and generation of statistics is greatly facilitated.

The data base for field information now totals 9500 samples from the west coast of Canada and the northern Pacific. This data base has been transferred to a microcomputer. Samples can be referenced by sample type, sample number, location, depth, analysis etc. and printouts of the field data and sample locations can be generated. In the next year the data base will be expanded to include the analytical data, and the plotting capability will be increased.

Eight groups external to the Pacific Geoscience Centre, six associated through joint projects, contributed samples in the past year. There were 21 requests for data and/or samples. *(Contact: T. Forbes.)*

# Marine Geology—Bedrock Geological Studies

## Lithoprobe Geological Studies

As part of the ongoing Vancouver Island Lithoprobe experiment, geological mapping at a scale of 1:50,000 was completed across central Vancouver Island (*A. Sutherland Brown*). Stratigraphic and structural relationships within the Paleozoic Sicker Group reveal long-lived caldera complexes and island arc volcanism associated with sulphide mineralization. Detailed studies along the Beaufort Range identified the primary Late Cretaceous timing of the Beaufort Range—Cowichan thrust fault system. *(Contact: C. Yorath.)*

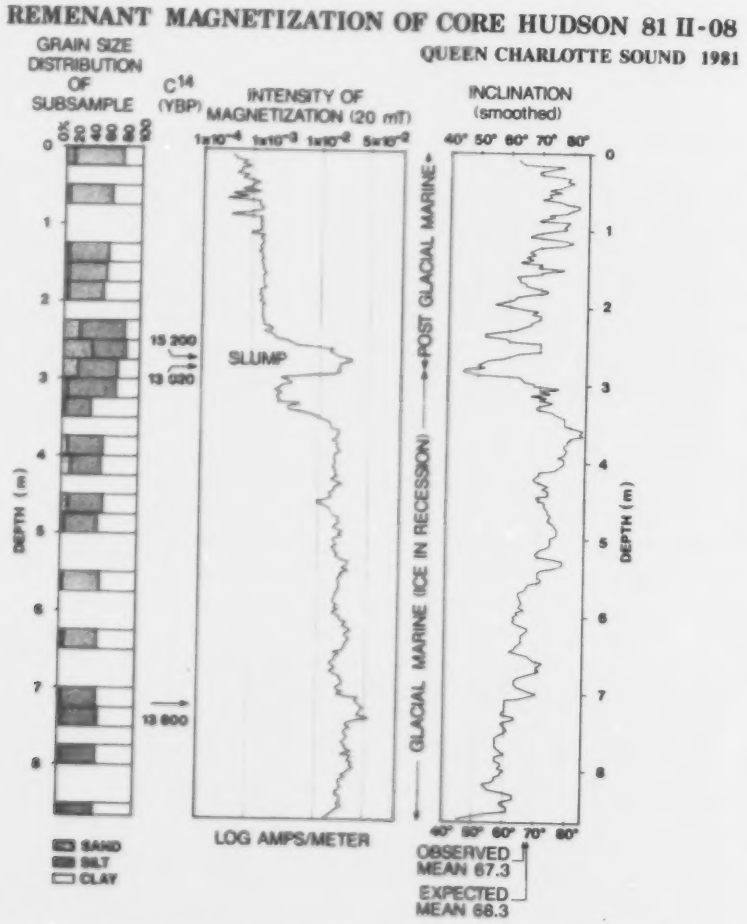
## Offshore Seismic Reflection Profiling

Approximately 900 km of multichannel seismic reflection profiles were shot across the shelf off the west coast of Vancouver Island under contract, and concurrent gravity and magnetic data also were obtained. About 515 km of the seismic data have been processed. Preliminary results reveal the Juan de Fuca plate dipping easterly beneath the continental margin, showing a correlation with the plate seen on the Vancouver Island Lithoprobe profile. Beneath the continental slope, easterly dipping thrust faults dislocate the sedimentary prism above the Juan de Fuca plate. High level structure appears to show tectonic wedging and delamination similar to that known to be present beneath the foothills of western Alberta. *(Contact: C. Yorath.)*

## Queen Charlotte Islands

Studies of the lavas of the Tertiary Masset Formation are part of a continuing series of investigations into the volcanics of the Insular Belt and adjacent deep ocean. Efforts in 1985 focussed on detailed stratigraphic and structural studies and 1:20,000 scale geological mapping in the McKay Range of central Graham Island and in parts of the Moresby Archipelago. New findings include lateral facies changes in these 21 to 17 million year old volcanics controlled by the proximity to local eruptive centres and by the subsequent effects of Late Tertiary structures which cut the volcanic pile. These structures include both

high angle strike slip faults (oriented ENE) and easterly dipping low angle faults (thrusts) which imbricate the section. Recognition of these structures is important to mining exploration both for their potential disruptive effect on old stratabound copper mineralization and their potential localizing effect on younger hydrothermal gold mineralization.




*Grain size distribution and magnetization of sediment in a core collected in a basin in southern Queen Charlotte Sound. Note distinct magnetic signature of different deposits and apparent regular secular magnetic variations in the upper, post-glacial sediments capping core. Once the chronology of these magnetic fluctuations is established, it should be possible to use paleomagnetism to correlate geologic events recognized in cores collected in different areas of the Sound. Note the excellent agreement between mean inclination and the expected axial dipole inclination indicating the absence of inclination error. (Research performed in association with PGC Paleomagnetics Laboratory.)*

In addition, more than 45 bitumen occurrences and tar and gas seeps have been located. Half of these hydrocarbon shows occur in rocks of the Masset Formation and are interpreted to be "escape oil" from older Jurassic source beds (approximately 200 million years old). Understanding the distribution of these hydrocarbon shows is vital to constructing subsurface petroleum exploration models for the Queen Charlotte Islands and the adjacent offshore regions. *(Contact: T.S. Hamilton.)*

## Geological Studies in the Strait of Georgia

The past year's activities in the Strait of Georgia have focussed on seismic stratigraphy and mapping of the unconsolidated Quaternary sediments which infill this marine basin. The total thickness ranges from near zero to more than 450 metres. The morphology of the underlying bedrock surface suggests a broad tectonic depression which has been incised in the Pleistocene by southeasterly flowing lobes of Cordilleran ice. The oldest Quaternary sediments (remnants of an earlier basin fill) are best preserved in sheltered interlobate areas as elongate drumlinoidal banks and ridges such as McCall and Halibut Banks. Early post-glacial sedimentation (about 10,000 B.P.) was restricted to the bathymetric depressions and was apparently derived by local reworking of older Quaternary deposits. By contrast, the more recent sedimentation is thickest off Roberts and Sturgeon Banks and clearly has the Fraser River as a sediment source. An understanding of these young sedimentary deposits is fundamental both to geotechnical assessments for submarine development and to an accurate representation of glacial and modern geological processes in the region. *(Contact: T.S. Hamilton.)*

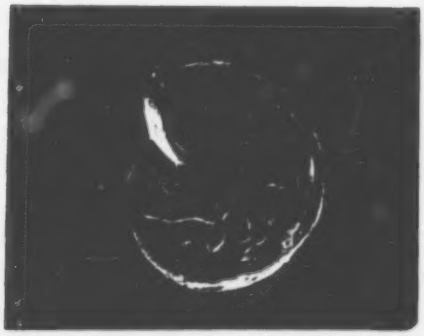
## Decade of North American Geology

As a contribution to Decade of North American Geology, a multi-volume series on the geology of North America, the volume on the Canadian Cordillera is nearing first draft completion. Twenty six chapters describe the geological architecture, tectonic history and resources potential of the Cordillera including the continental margin. Contributions from the Pacific Geoscience Centre include chapters and sections on Upper Jurassic to Paleogene stratigraphic assemblages, Neogene assemblages, structural style and resources potential of the Insular Belt, modern plate tectonic regime, Cordilleran geophysics and paleomagnetism. *(Contact: C. Yorath.)*

# Palaeontology

Activities in palaeontology and biostratigraphy in 1985 centered on the Jurassic and Cretaceous foraminifers and the stratigraphy of the Queen Charlotte Islands. Several new stratigraphic units have been recognized, some of which have significance as primary hydrocarbon source beds, others may prove to be good stratigraphic hydrocarbon traps in subsurface.

Lenticulina d'orbignyi (Roemer)



Lenticulina gottingensis (Bornemann)

Lenticulina prima (d'Orbigny)

Lenticulina sp. T1

Kinkelinella sp.

Citharina sagittiformis (Terquem)

*Scanning electron microscope micrographs of Jurassic foraminifers of the Queen Charlotte Islands.*

The Jurassic and Cretaceous of the Queen Charlotte Islands spans approximately 120 million years between 200 to 87 million years ago. The rocks are composed of a complex sequence of mixed volcanic and sedimentary rocks which carry rich faunas of both macro and microfossils. There are an estimated 700 species of foraminifers throughout this section which provide an excellent means of dating the rocks, and indicate the environments in which the rocks were deposited. *(Contact: B.E.B. Cameron and M. Johns.)*

# Multiparameter—Geophysical Surveys

Systematic magnetic, gravity and bathymetric surveys have been conducted over the Canadian Exclusive Economic Zone to help assess the economic potential of the region and its tectonic framework.

During this year's marine program 9000 kilometres of geophysical data were collected on a 4 week cruise aboard CSS *Parizeau*. The region surveyed was between 46° and 51°N and from 100 to 200 nautical miles offshore. The 1985 cruise marked the culmination of a multiyear program which started in 1973. Approximately 93,000 kilometres of data have been obtained in an area from the Strait of Juan de Fuca to Dixon Entrance

out to 200 n.m. offshore. The line spacing has typically been 5 km at the inshore continental shelf ends of the lines, to 10 km at the 200 n.m. limit.

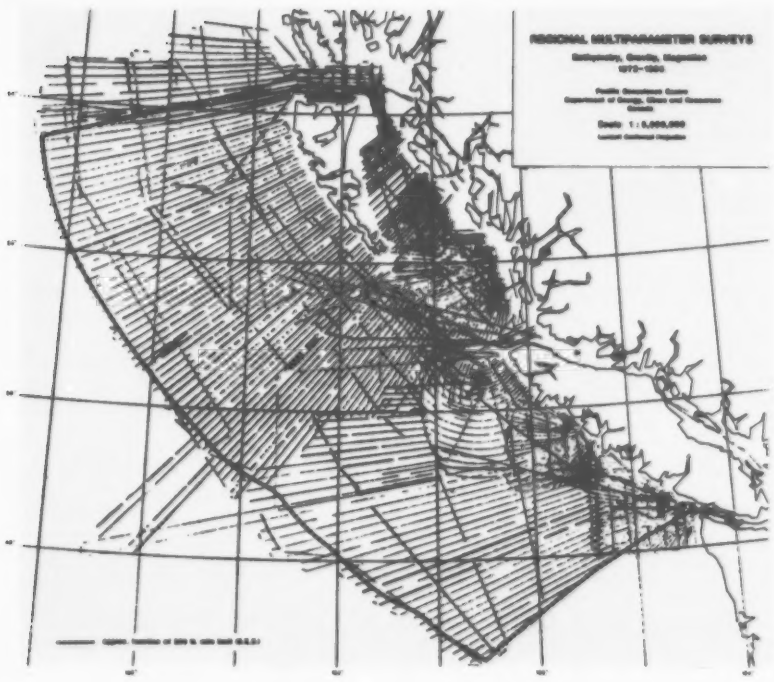
The gravity data set of some 47,000 survey points has recently undergone a network adjustment in the Ottawa gravity laboratory involving approximately 2400 crossovers yielding a standard deviation of 1.05 mGals (1 part in 1,000,000 of the earth's gravity). Similar processing is underway for the magnetic data which will be released in 1986.

In addition to the major offshore survey, 750 kilometres of gravity and bathymetric data were collected in Georgia Strait in 1985. *(Contact: R.G. Currie and D.A. Seemann.)*

## Juan De Fuca Ridge and Offshore Mapping

Detailed SEABEAM high resolution swath bathymetry mapping efforts are continuing in a cooperative effort with S. Hammond of the National Oceanographic and Atmospheric Administration (NOAA), with the production of several new 1:50,000 ten m contour map sheets and 1:250,000 regional compilations over the northern Juan de Fuca Ridge system. The maps continue to be put to extensive use both for direct tectonic interpretation and as base maps for geophysical and geological studies using deep-towed and bottom-deployed instruments, cameras and sampling, and using the research submersibles *Alvin* and *Pisces*. *(Contact: E. Davis, R.G. Currie and B. Sawyer.)*

Mapping of the seafloor off western Canada is also continuing, in cooperation with the Hawaii Institute of Geophysics, with the SeaMARC II acoustic imaging system. Extensive surveys were completed this year over the central Juan de Fuca and northern Explorer Ridges, and the Vancouver and Queen Charlotte Islands continental margins. Features of particular interest included the highly asymmetric distribution of off-axis volcanism near the Explorer and Juan de Fuca Ridge crests and the frequent occurrence of massive slope failures along the first compressional fold of the underthrusting zone at the base of the Vancouver Island continental slope. *(Contact: E. Davis, R.G. Currie and B. Sawyer.)*




*Composite ship's track showing coverage obtained from 1972 to 1985 inclusive.*

# International Ocean Drilling Project

In 1984 Canada became a member of the International Ocean Drilling Project (ODP). This project will lead both to deep sea boreholes adjacent to Canada that will make critical contributions to our understanding of the Canadian offshore and to the involvement of Canadian scientists in the forefront of marine geoscience research around the world. The involvement of PGC scientists in specific cruises of the drilling ship *JOIDES Resolution* is planned starting in 1986. At present PGC has extensive involvement through membership on the Canadian National Committee for ODP, and on the advisory panels: Central and Eastern Pacific Regional Panel (CEPAC), Western Pacific Panel (WPP) and Southern

Oceans Panel (SOP). Several papers on the crustal structure, physical properties and hydrothermal circulation regime of a region of the Mid-Atlantic Ridge from a previous drilling leg were published this year. *(Contact: R.D. Hyndman, B.D. Bornhold, C.J. Yorath and E.E. Davis.)*

# Seismological Service

The Seismological Service provides earth scientists, civil engineers, resource development industries and the public with basic earthquake data and with research information concerning natural and induced earthquakes, ground motion, seismic risk, earth structure, and nuclear explosions. This is accomplished through a network of seismological stations, including standard and regional stations, two telemetered arrays, strong motion accelerographs and special installations. A total of some 50 seismograph stations are now operating in western Canada.

## Special Seismic Networks

The Western Canada Telemetered Network (WCTN) provides centralized, on-line monitoring of seismicity in southwestern British Columbia. Eighteen stations are recorded at the Pacific Geoscience Centre (PGC), including 3 stations of the University of B.C. network.

The regional network in the Queen Charlotte area has been strengthened this year by the addition of three stations on Moresby Island and one station in Prince Rupert. The Beaufort-McKenzie regional network, formerly operated in cooperation with Dome Petroleum Ltd., has been restructured and is now operated by PGC. Data from the coastal stations at Komakuk Beach and Single Point are now sent on telephone lines to Inuvik where they are recorded on paper. The network is completed by regional stations at Sachs Harbour and Dawson.

The strong motion seismograph network in western Canada consists of instruments designed to operate and record ground acceleration only when very strong (½% of normal gravity or larger) earth motion occurs. During 1984, one new instrument was added in the Queen Charlotte area for a western Canada total of 36 accelerographs. A review of the growth and current status of the Canadian strong motion program was prepared for the International Association of Seismology and Physics of the Earth's Interior. The Miramichi, New Brunswick earthquake series of 1982 has

given a significant impetus to the development of the Canadian strong motion instrumentation program. The accelerograph network of the National Research Council is now under the direction of Earth Physics Branch and extra funding has been made available for upgrading the western network. Three strong motion instruments were installed in the Nahanni area of S.W. Northwest Territories following an October event. Unique strong motion records were obtained by the instruments from a subsequent M = 6.9 event in December in the same area. Two of the instruments were very close to the hypocentre and recorded maximum horizontal acceleration of some 1.25 g and vertical acceleration of over 2g. *(Contact: D.H. Weichert.)*

*One kilometre-wide landslide triggered by October 5, 1985 Nahanni earthquake.*

## Seismic Risk

PGC continues to supply site specific seismic risk calculations. Use of the extreme value method of Gumbel, as specified in past versions of the National Building Code of Canada, has been discontinued. Calculations

are now based on Cornell's method as described in the 1985 edition of the Code. *(Contact: D.H. Weichert.)*

## Special Earthquake Studies

Expansion of the telemetered seismograph array in late 1984 has made it possible to study the focal depths and focal mechanisms of microearthquakes in the central region of Vancouver Island. Preliminary analysis suggests almost all earthquakes are within the subducted plate beneath Vancouver Island and none have mechanisms consistent with slippage on the subduction thrust interface between the two plates.

A comprehensive data base of earthquakes and arrival times for the region west of Vancouver Island has been compiled. *(Contact: G.C. Rogers.)*

## Western Canada Seismicity

The Pacific Geoscience Centre is responsible for locating all earthquakes recorded in western Canada for inclusion in the National earthquake data file. During 1985, approximately 1,000 earthquakes were located. The two largest earthquakes, magnitude 6.6 on October 5 and magnitude 6.9 on December 23, occurred in the Nahanni area of the Mackenzie Mountains about 160 km west of Fort Simpson, N.W.T. These were the two largest earthquakes on land in Canada in about the last 40 years. Both were very widely felt over most of western Canada. No serious damage was reported, mainly due to the low population density in the epicentral region. Field surveys were conducted after each event to determine the nature and extent of the aftershock sequences and to examine macroseismic effects such as landslides. Aftershock activity is continuing with events as large as magnitude 5. *(Contact: R.B. Horner.)*

Elsewhere in western Canada, 14 other earthquakes were reported felt. These included four near southern Vancouver Island, one in southern mainland B.C., two on the Queen Charlotte Islands, three in southwestern Alberta, one in Saskatchewan and three in the southwest Yukon Territory. *(Contact: R.B. Horner, G.C. Rogers and D.H. Weichert.)*

# Gravity

The principal mandate of the Gravity Service is to establish the shape of the geoid in Canada to the highest standards and to determine the value of gravity on a regional basis over the Canadian landmass and offshore areas. The regional gravity data are used in both the determination of crustal structure and the evaluation of resources and are critical to the operation of inertial navigation systems used by defence and other agencies.

*Measuring gravity at a surveyor's cairn in the Ogilvie Mountains, Yukon.*

In conjunction with the Lithoprobe program, a detailed gravity study was conducted this summer in the area of the proposed transect in the Mackenzie Basin between Inuvik and the Beaufort Sea. Gravity measurements collected from over 200 stations will provide valuable information on crustal thicknesses and aid in the interpretation of seismic reflection data to be collected along the transect early in 1986.

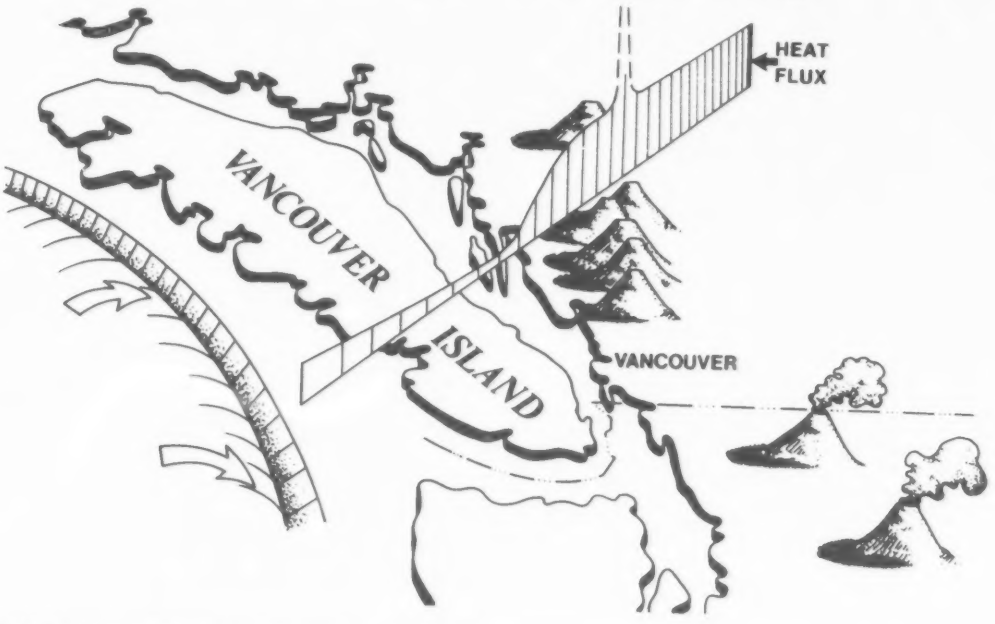
The digitizing of one kilometre elevation/depth information used in the computation of terrain corrections was continued under contract. Most of British Columbia (including a large portion of the offshore area) and the Yukon Territory have now been covered as well as adjoining areas in Alberta, Northwest Territories, Alaska and Washington. The Digital Terrain File which resides in a System 2000 data base maintained by the Gravity Data Centre, Ottawa now contains approximately 2.3 million spot elevations and water depths.

The marine component of the gravity program was active this year and is discussed in the "Multiparameter-Geophysical Surveys" section. A

contract for an extensive underwater gravity survey off the Canadian east coast was also managed on behalf of the Department of National Defence. *(Contact: J.F. Sweeney, D.A. Seemann and J.B. Boyd.)*

# Geothermal Studies

In 1985 the geothermal program continued its studies related to understanding the western Canada and offshore thermal regime, including its relation to tectonic processes and to geothermal energy potential. The measured thermal parameters include field measurement of surface heat flux (the product of vertical temperature gradient multiplied by the thermal conductivity of the rocks) from boreholes and from seafloor probes and of the heat generation from naturally occurring isotopes of uranium, thorium and potassium. Studies covered a wide range of geological and geophysical interests, including the processes involved at the Juan de Fuca Ridge, the aging and cooling of the plates, the subduction along the west coast margin, tectonic and volcanic processes in the Cordillera and the potential for geothermal energy.




*Variation in heat flux as a consequence of the subducting oceanic plate.*

## Continental Geothermal Studies

The analysis of heat flux data along the Vancouver Island Lithoprobe Profile showed that the main, deep seismic reflectors are nearly isothermal, and the deepest is approximately 450°C. Thermal modelling of the subducting plate indicates that it must be kept cool in order to have the brittleness to sustain earthquakes. Consequently, fluid flow and/or endothermic metamorphic reactions must be occurring along the horizons defined by the dipping, isothermal seismic reflectors.

An 11m telemetry heat flow probe was built, tested and used in the northern B.C. fiords. This probe allows a greater depth of penetration into the soft bottom sediments, helping to overcome transient problems caused by changes in bottom water temperatures of the fiords.

Two boreholes were drilled in the Fraser Valley to help define the heat flux distribution along an east-west profile. The object was to look for the large heat flux transition which occurs to the north along Jervis Inlet, 30 km seaward of the Garibaldi Volcanic Belt and for possible low grade geothermal energy potential in the upper Fraser Valley. Geothermal data were also obtained from boreholes drilled for mineral exploration near Duncan, Rossland, Adams Lake and Harrison Lake, B.C., as well as in southern areas of the Yukon. *(Contact: T. Lewis and W. Bentkowski.)*

## Oceanic Geothermal Studies

One exemplary study was completed over the northern Juan de Fuca Ridge at a location where the rift axis is completely buried by turbidite sediments from the nearby continental margin. A number of unusual mounds observed in the new SEABEAM bathymetry and previously published SeaMARC II acoustic image data along the eastern side of the sediment-filled rift valley were suspected to be of hydrothermal origin. A detailed study of these features was completed using piston coring, bottom photography, heat flow, and high and medium frequency seismic reflection profiling. The presence of very large heat flow anomalies in the vicinity of the mounds and the recovery of hydrothermal sulphide sediments from one of the mounds verified their hydrothermal origin. The mounds appear to be present-day analogues to many massive sulphide ore deposits found now on land. *(Contact: E. Davis and B. Bornhold.)*

The analysis of high-accuracy heat flow measurements from several Jurassic basins of the western Pacific was completed, and the data verify

that the heat flow in these basins is too high to be explained by any simple cooling history. A major lithospheric reheating event since the time of seafloor creation is implied. *(Contact: E. Davis.)*

# Geomagnetism

The Geomagnetism Group has programs in observatory monitoring of changes in the geomagnetic field, in the use of rapid variations to determine earth structure and properties and paleomagnetism.

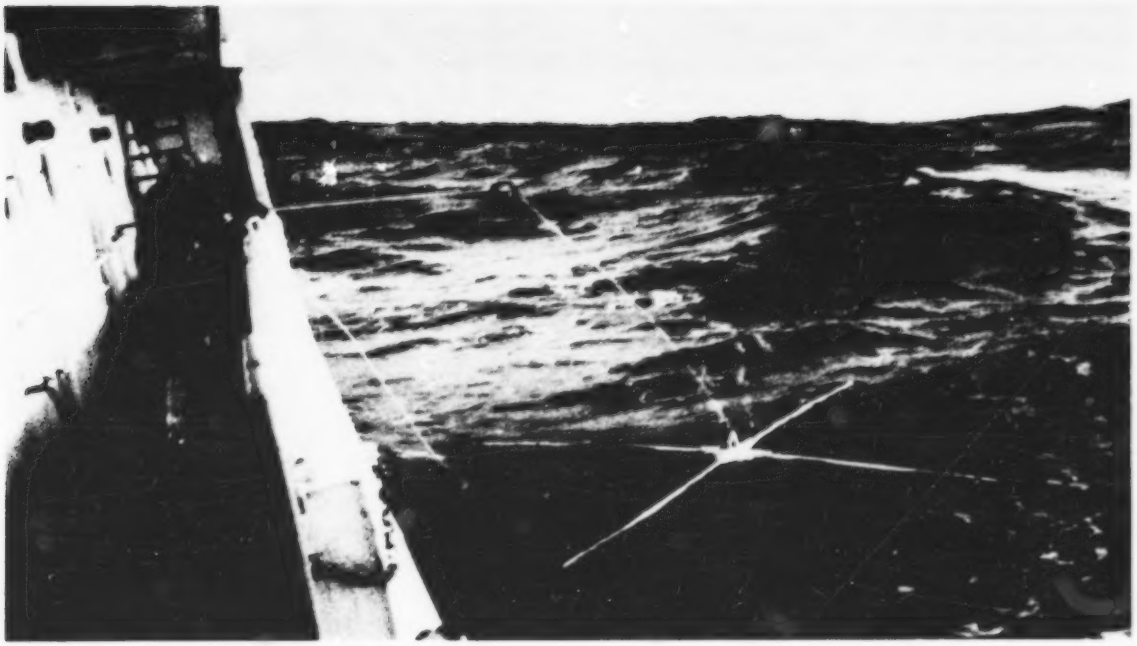
## The Geomagnetic Field

To be utilized for navigation, the magnetic field and its gradual change with time must be determined as a function of latitude and longitude. In addition, changes must be monitored to correct for transients in magnetic survey data and for a variety of other purposes. As part of the Canadian Geomagnetic Network of 13 primary observatories, PGC operates the Victoria Geomagnetic Observatory on property at the Dominion Astrophysical Observatory. *(Contact: L. Law and D. Auld.)*

## Geomagnetic Variations

Temporal variations in the earth's magnetic field provide an electromagnetic source with which to probe the earth's electrical conductivity structure using a technique called magnetotellurics. Electrical conductivity is an important parameter in understanding the active tectonic regions on the west coast. Deep zones of high conductivity, related to high temperatures and partial melting, determine the maximum thickness of the cold lithosphere riding over the asthenosphere. Conductive zones at shallow depths occur in regions with geothermal resource potential.

An international electromagnetic induction experiment to investigate the structure of the Juan de Fuca Plate was carried out during 1985. This project, called EMSLAB (ElectroMagnetic Sounding of the Lithosphere—Asthenosphere and Beyond), included the largest array of land and seafloor magnetometers ever deployed. The array spanned from the ridge, where new material forms, across the Cascadia Basin to the coastal region where the Juan de Fuca Plate sinks deep below North America,



*Recovery of ocean bottom instrument used in a EMSLAB project.*

and to the other side of the Cascade Volcanoes, produced by the remelting of the plate. The data are currently being analysed. The results will yield an image of an oceanic plate from birth to death.

Results from controlled-source electrical soundings and heat flow measurements obtained near the Juan de Fuca Ridge in 1984 show that this combined analysis greatly constrains most of the physical properties of the sediments.

A two-dimensional electrical conductivity model has been constructed to simulate the subduction of the Juan de Fuca Plate beneath Vancouver Island, Strait of Georgia and coast ranges of British Columbia. The model results are in excellent agreement with the magnetotelluric responses that were obtained on Vancouver Island along the Lithoprobe transect in 1984. A good conductor was located dipping beneath western Vancouver Island which was coincident with the strongest seismic reflector and taken to be associated with the top of the downgoing Juan de Fuca Plate. The conductivity of this region suggests that the materials are porous (between 1% - 4%) and saturated with saline fluids.

The monitoring of changes in apparent resistivity, related to the increase in tectonic strain in central Vancouver Island, continued at two sites. Following results from a site located on a fault zone in Japan that showed a marked decrease in electrical potential preceding a magnitude 4.9 earthquake, site testing was completed for a third station directly on the Beaufort Range fault. This fault is thought to be the locus of the major 1946 earthquake.

A preliminary map was compiled in digital format showing the major terrane boundaries for the Juan de Fuca map area. An overlay of the terrane map allows correlations to be made with other compilations of geophysical data in the Juan de Fuca map series, namely magnetic anomalies, seismicity, heat flux, and gravity anomalies. *(Contact: L. Law, J. DeLaurier, D. Auld and D. Nobes.)*

## Paleomagnetism

Paleomagnetic work at PGC is concerned primarily with the tectonics of the Cordillera and the western Arctic, and with magnetostratigraphic studies. During the last decade, geological and geophysical studies have shown that the Cordillera comprises a number of distinct crustal blocks. Paleomagnetic work has shown that these blocks have been transported from the south by distances of over 1000 km. This discovery that the western Cordillera is a collage of accreted crustal fragments has led to a profound revision of ideas about the origin of this and other mountain belts.

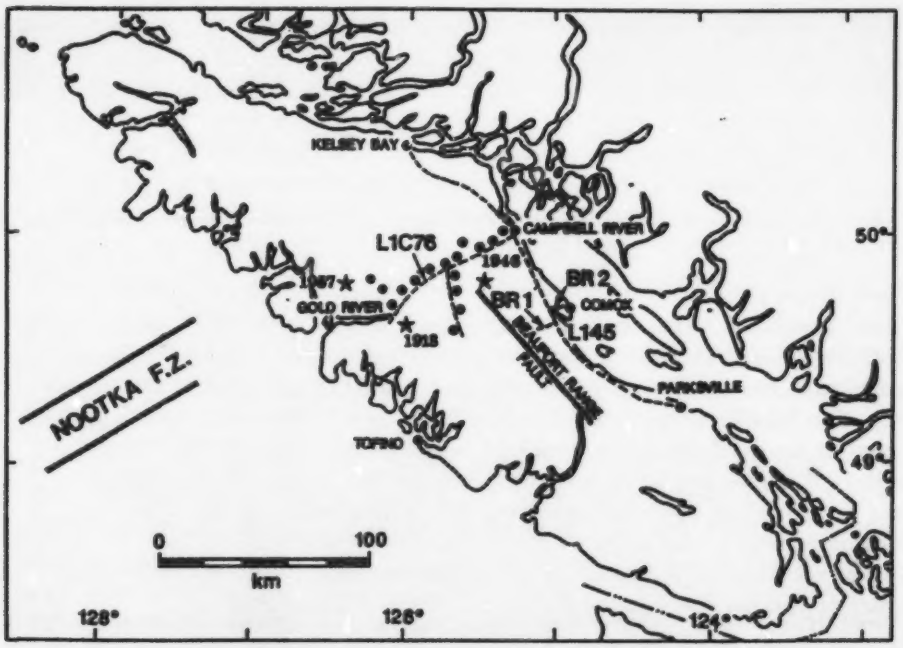
Three major programs are underway. The objective of the first is to collect a suite of rocks along a traverse across the Cordillera from Vancouver Island to the Rockies in order to determine the relative latitudes of the various crustal elements at different geological instants in time. The Middle Cretaceous (100 Ma) traverse is now well in hand, and traverses for the Late Triassic—Early Jurassic (200 Ma) and the Early Tertiary (Eocene) are in process of development. The second program calls for sampling from the northern rim of the Sverdrup Basin in Ellesmere Island. The third program is concerned with the study of secular variation of the geomagnetic field recorded in recent sediments, in fiords and on the continental shelf of British Columbia.

The main collections made in 1985 were in collaboration with Queens and Carleton Universities. We have also made considerable progress in compiling a Canadian catalogue of paleomagnetic results, and have completed a review of all paleomagnetic work in the Cordillera, in which

we have attempted to relate the motions of various terranes to the motions of the oceanic plates to the west. *(Contact: E. Irving and P.J. Wynne.)*

# Geodynamics

The current focus of geodynamic studies on the west coast of Canada is contemporary crustal deformation effects at the active plate margin. The scientific objectives include gaining a better understanding of current plate interactions in the Juan de Fuca subduction zone, and relating contemporary secular deformation processes to current seismicity and potential major future earthquakes.




*Location of the geodetic surveys carried out on central Vancouver Island for the purpose of measuring deformation. Dots represent precise gravity station and the fine dashed lines (L1, L2, L3) show lines of repeated levelling. Stars annotated with a date mark the epicentres of the three large (M greater than 6) earthquakes which occurred this century.*

Three geodetic measurement techniques are being applied in the area of central Vancouver Island to monitor on-going crustal deformation: repeated precise gravity, vertical control (levelling), and horizontal control (trilateration, triangulation) surveys.

Precise gravity surveys which monitor a combination of relative changes in elevation and crustal densities were initiated in 1977. A reoccupation of the network of stations established at that time was again completed by contract in August 1985. Most of the gravity changes so far observed are less than 15 $\mu$Gal and can be related to local effects, i.e. changes in water levels of the Strathcona Reservoir or changes in the local groundwater table. No significant long-term linear gravity trends have been resolved at any of the network sites.

Repeated precise elevation measurements of benchmarks along highways are used to measure regional tilting of the earth's surface. During the past year, levelling was again carried out by the Geodetic Survey of Canada between Campbell River and Gold River in order to check for continued east-west tilting suggested by a comparison of the 1976 and 1981 surveys. Unfortunately, the presence of systematic errors in the earlier surveys prevents a clear resolution of current tilt rates. However, the best estimate is that the Campbell River region is uplifting with respect to Gold River at a rate of 1 or 2 mm/a. As part of this work, a thorough investigation of the effects of sytematic errors on these levelling data was carried out. It appears that the 35 mm of uplift of Campbell River with respect to Parksville determined from surveys carried out in 1977 and 1984 is real and cannot be accounted for by systematic errors. It could reflect deformation associated with a major earthquake cycle.

Trilateration measurements using laser-ranging instruments can monitor changes in distances as small as a few millimetres over tens of kilometres. A network of mountain-top stations, established in 1981 in the Gold River area, was again surveyed by the Geodetic Survey of Canada in July 1985. These newer data indicate an on-going shear strain in this region of about 0.15 $\mu$ strain/a (i.e. 0.15 parts in a million) of relative shortening in a northeast direction. This direction of compression is in agreement with the direction of convergence of the Juan de Fuca Plate with the North America Plate along the margin to the west.

As part of the NASA Crustal Dynamics Project which is studying deformation on a more global scale, the second occupations of the Whitehorse and Penticton VLBI (Very Long Baseline Interferometry) sites by the NASA mobile radio antenna were completed in August 1985. The Whitehorse site serves as a reference location in the study of plate

deformation in Alaska, while the Penticton site is being used in conjunction with the Yellowknife, N.W.T. and Algonquin, Ont. sites to monitor crustal deformation of the North American craton. Unfortunately, technical problems with the antenna pointing system resulted in poor quality data which prevented the calculation of any baseline distances involving these two sites for this field campaign. The project is continuing and it is hoped that the 1986 data will provide the first continental-scale strain estimates for Canada. *(Contact: H. Dragert.)*

## Boundary Studies

As part of the Offshore Bilateral Boundary Geoscience Studies Program a wide range of geoscience studies were carried out along the offshore Juan de Fuca boundary. They are described in other sections. The other major Boundary Studies activity was the archiving of a bibliographic geoscience reference data base for the western Canada (Juan de Fuca, Dixon Entrance and Beaufort Sea) offshore international boundary areas. The computer data base is now largely complete. This activity, carried out in cooperation with the Atlantic Geoscience Centre, Institute of Sedimentary and Petroleum Geology, Polar Continental Shelf Project and Earth Sciences, EMR, Ottawa, through contracted and in-house studies, has assembled more than 4000 tailored bibliographic citations, 500 map/charts and a significant collection of geoscience cruise information for both the Juan de Fuca and Beaufort Sea regions.

The completion phases of this project will include optimization of retrieval software and a scientific appraisal and analyses of the data base information and marine studies mentioned elsewhere in this annual review. Presentation of these analyses will be made to the Department of External Affairs. Open File release of the assembled data files and information catalogues is proposed for late 1986. *(Contact: J.B. Boyd.)*

## Technical Support

Technical Services provides electronic, mechanical and logistic support to all operating groups within PGC—both land and marine. Also, some technical support is provided to university groups and other divisions of

EMR engaged in earth sciences research. These groups include Royal Roads Military College, Simon Fraser University, the University of British Columbia and the University of Toronto, as well as Atlantic Geoscience Centre and GSC, Ottawa. The principal demand on Technical Services is the acquisition, operation and maintenance of scientific instrumentation. The year 1985 was the busiest season yet, with 19 cruises being supported.

The Sedimentology Laboratory now digitally records sediment grain size parameters as determined by x-ray sedigraph for silts and clays, and settling tube for sands. The IBM-PC based system makes data acquisition, parameter computation and data storage and retrieval much more rapid and accurate. *(Contact: T. Forbes, G. Horel and W. Hill.)*

The Paleomagnetic Laboratory ran extensive tests on a new Schonstedt Spinner Magnetometer (SSM-2) with TSD-1 furnace and an IBM-PC based controller/data logger. Also preliminary work was carried out to replace an aging LS1-II computer and Silent 700 terminal with an IBM-PC. *(Contact: E. Irving, P.J. Wynne and W. Hill.)*

An IBM-PC based data acquisition system to replace the PHAS system was successfully tested and is currently being modified in terms of both hardware and software. In its final form the system will acquire navigation information from hyperbolic LORAN C, range-range LORAN C, GPS and TRISPONDER; acquire additional data through 10 channels i.e. bathymetry, magnetics, gravity; pass data to an IBM-AT via a networking system for post-processing and track plotting. *(Contact: G. Horel, W. Hill and I. Frydecky.)*

A further updating of sidescan sonar capability was realized with the purchase of a 100 kHz towfish and eight channel analog recorder (4 AM and 4 FM channels). Sub-bottom profiling capabilities were enhanced with the purchase of a 3.5 kHz pinger, Teledyne 50 element-single channel streamer and two waterguns (15 cubic inch and 80 cubic inch). *(Contact: I. Frydecky, R. Macdonald and M. Bone.)*

Piston coring equipment was modified to allow instrumenting the barrels for heat flow work. A larger diameter, heavier corehead was designed to carry and protect the heat flow instrument cylinders. *(Contact: E. Davis and R. Macdonald.)*

Five PGC Ocean Bottom Magnetometers were deployed for periods of 60 to 90 days in conjunction with the EMSLAB project. One of these magnetometers remains unrecovered with dwindling hopes for retrieval.

A contract is in progress with Polar Tech Ltd. of Sidney, B.C. for

development and construction of an improved telemetering heat probe for in-situ ocean-bottom measurements of thermal gradients and conductivity. The new probe will feature solid-state data logging with interactive operator control of all control parameters.

An 11-metre long thermistor probe was fabricated and used with partial success for deep-penetration measurement of thermal gradients and conductivity in soft sediments. A second 11-metre unit has been mechanically constructed and both probes are in the process of being equipped with thermistors for use in the Queen Charlotte Sound area during 1986.

The VAX 11/750 system has been installed for the analysis of seismic data acquired by WCTN. In addition, two PDP 11/73 systems have been ordered to replace the existing PDP 11/24 and 11/40 systems for data acquisition from the 18 seismic telemetry stations of WCTN.
*(Contact: M.N. Bone, A. Whitford and R. Baldwin.)*

# APPENDIX I

## Contracts Awarded 1985

### A. Department of Fisheries and Oceans

*Measurement of Predation Rates on Small Zooplankton by* Euchaeta elongata *and* Euphasia pacifica
Edward Anderson Marine Sciences, Sidney, B.C. ..... $ 4,392

*Analysis of Samples & Archiving of Data, La Perouse Monitoring Project–Zooplankton Samples*
Edward Anderson Marine Sciences, Sidney, B.C. ..... 8,021

*Development of Software on the IOS Image Processing System*
Apocalypse Enterprises Inc., Victoria, B.C. ..... 2,000

*Development of Software for the IOS Image Processing System*
Apocalypse Enterprises Inc., Victoria, B.C. ..... 29,200

*Develop a Ship Administration Information System Programme*
Apocalypse Enterprises Inc., Victoria, B.C. ..... 5,600

*Compilation of Existing Chemical Oceanographic Data Sets for the Canadian West Coast Offshore Waters, Georgia Strait, Juan de Fuca Strait, Canada Basin and Arctic Ocean*
Arctic Laboratories Ltd., Sidney, B.C. ..... 16,650

*Arctic Chemical Oceanographic Data Report Acquisition*
Arctic Laboratories Ltd., Sidney, B.C. ..... 10,640

*Compilation of Northwest Passage Zoobenthos Data*
Arctic Laboratories Ltd., Sidney, B.C. ..... 10,125

*Compilation of Northwest Passage Zoobenthos Data (Continued)*
Arctic Laboratories Ltd., Sidney, B.C. ..... 23,202

*Technical and Oceanographic Support with Gauge Mooring at Pond Inlet, N.W.T.*
Arctic Research Establishment, St. Catharines, Ontario ..... 2,500

*Compilation and Appraisal of Existing Physical Oceanographic Data in the Canadian Basin of the Arctic Ocean*
Arctic Sciences Ltd., North Saanich, B.C. ..... 28,083

*Continuation of Acoustic Measurements of Flows in Channels*
Arctic Sciences Ltd., North Saanich, B.C. .... $ 39,996

*Development of Scintillation Radio Link and Power Transmitter System*
Arctic Sciences Ltd., North Saanich, B.C. ..... 47,860

*Compilation and Appraisal Report for Physical Oceanographic Data in Queen Charlotte Sound, Hecate Strait and Dixon Entrance*
Arctic Sciences Ltd., North Saanich, B.C. ..... 9,844

*Preparation of a Compilation and Appraisal Report for Physical Oceanographic Data*
Arctic Sciences Ltd., North Saanich, B.C. ..... 31,377

*Compilation of Oceanographic Data of the Nanoose Bay Underwater Test Range*
Arctic Sciences Ltd., North Saanich, B.C. ..... 39,134

*Upgrading Oceanographic Data Information System (ODIS)*
Arctic Sciences Ltd., North Saanich, B.C. ..... 3,500

*Development of a Meteorburst Drifting Buoy System, Phase I*
Arctic Sciences Ltd., North Saanich, B.C. ..... 40,000

*Testing of Real-time Decoding System and Design of Data Logging System*
Arctic Sciences Ltd., North Saanich, B.C. ..... 34,055

*Preparation of a Compilation and Appraisal Report for Physical Oceanographic Data*
Arctic Sciences Ltd., North Saanich, B.C. ..... 5,036

*Preparation of Report on the Nanoose Range Oceanographic Data 1967-1984*
Arctic Sciences Ltd., North Saanich, B.C. ..... 5,991

*Development of a Meteorburst Drifting Buoy System, Phase II*
Arctic Sciences Ltd., North Saanich, B.C. ..... 210,000

*Development of Specifications to Ocean Data Inventory System (ODIS)*
Arctic Sciences Ltd., North Saanich, B.C. ..... 4,995

*Study Ice Conditions Relevant to the Recovery of Current Meter Moorings in the Beaufort Sea*
Arctic Sciences Ltd., North Saanich, B.C. ..... 4,838

*Development and Theory of a Second Generation Scintillation Current Measurement System*
Arctic Sciences Ltd., North Saanich, B.C. .... $ 163,087

*Recovery of WOTAN Instruments from CASP Experiment*
Arctic Sciences Ltd., North Saanich, B.C. ..... 8,268

*Study Effects of Increased $CO_2$ on Temperature and Precipitation*
Atmospheric Dynamics Corp., Victoria, B.C. .... 10,064

*Incorporation of Ice Cover in Storm Surge Model*
Atmospheric Dynamics Corp., Victoria, B.C. .... 63,830

*Incorporation of Ice Cover in Storm Surge Model (Phase II)*
Atmospheric Dynamics Corp., Victoria, B.C. .... 66,546

*Modification to Storm Surge Model*
Atmospheric Dynamics Corp., Victoria, B.C. .... 45,975

*Study of Contours of Hecate Strait 1984 in NTX Format*
Barrodale Computing Services Ltd., Victoria, B.C. ..... 3,990

*Demonstration of the Hydrographic Contouring System on the VAX*
Barrodale Computing Services Ltd., Victoria, B.C. ..... 4,165

*Analysis of Test and Flight Data from the FLI*
G.A. Borstad Ltd., Sidney, B.C. ..... 40,184

*Collection and Analysis of Satellite and Aircraft Imagery for Studying Beaufort Sea Ice Movement*
G.A. Borstad Ltd., Sidney, B.C. ..... 30,655

*Develop a Computer Sorting Algorithm for Ship-of-Opportunity Data*
Broccoli Bros., Sidney, B.C. ..... 1,214

*Ship-of-Opportunity Sampling of Planktonic Ecosystem off Pacific Coast of Canada*
Broccoli Bros., Sidney, B.C. ..... 7,293

*Measurement of Phyto-adaption of Marine Phytoplankton to Fluctuation of Light in Turbidostat Culture*
Broccoli Bros., Sidney, B.C. ..... 5,638

*Analysis of Zooplankton Time Series Along Drifter Trajectory*
Broccoli Bros., Sidney, B.C. ..... 29,343

*Field Measurement of Spatial and Temporal Variability of Photosynthetic Parameters*
Broccoli Bros., Sidney, B.C. ..... 2,008

*Comparison of Syledis/GPS Positioning*
Canadian Engineering Surveys Co. Ltd., Edmonton, Alberta ..... $ 73,000

*Provision of Navigation and Survey Positioning West of Herschel Island*
Canadian Engineering Surveys Co. Ltd., Edmonton, Alberta ..... 40,209

*Multi-disciplinary Geophysical and Hydrographic Survey off the Yukon Coast*
Cansite Surveys Ltd., Calgary, Alberta ..... 65,149

*Develop a Model to Predict Effects of Buried Underwater Blasting Charges on Fish Populations in Shallow Water Areas*
Coastline Environmental Services Ltd., Vancouver, B.C. ..... 103,280

*Hydrographic Surveys of the Kitimat/Stewart Areas in Northern British Columbia*
Coast Pilot Ltd., Sidney, B.C. ..... 97,344

*Literature Review and Preparation of a Report on the Biological and Fisheries Aspects of the Carbon Dioxide Problem*
CPRO Computing Enterprises Ltd., Victoria, B.C. ..... 7,500

*Analysis of the Relationship between Sound Scattering and Temperature Microstructure and Bubble Populations*
G. Crawford, Victoria, B.C. ..... 2,560

*Arctic Pack Ice Driving Forces*
Croasdale & Associates, Calgary, Alberta ..... 217,859

*Compilation of Oceanographic Data of the Nanoose Bay Underwater Test Range*
Dobrocky Seatech Ltd., North Saanich, B.C. .... 5,660

*Modifications to Loran C Drifting Buoys*
Dobrocky Seatech Ltd., North Saanich, B.C. ..... 29,981

*Evaluation of Metallothionein as an Environmental Indicator of the Biological Effects of Metal Levels in Natural Waters*
Dobrocky Seatech Ltd., North Saanich, B.C. .... 236,026

*Survey of Tuktoyaktuk–Driftwood*
Dobrocky Seatech Ltd., North Saanich, B.C. .... 9,620

*Drift Study to Assess Predictive Capability of a Numerical Model of the Fraser River*
Dobrocky Seatech Ltd., North Saanich, B.C. ..... 1,561

*Evaluate Application of Acoustically Traced, Free Drifting "RAFOS" Floats*
Dr. Dosso, University of Victoria, Victoria, B.C. .. 9,000

*Historical Drill Waste Discharge*
ESL Environmental Sciences Ltd., Vancouver, B.C. ..... $ 31,946

*Inventory of Marine Plankton Data for Canadian Beaufort Sea*
ESL Environmental Sciences Ltd., Vancouver, B.C. ..... 29,907

*Study of Variations in Somatic Characteristics of Aquatic Oligochaetes*
E.V.S. Consultants, N. Vancouver, B.C. ..... 42,573

*Identification and Enumeration of Marine Phytoplankton at Ocean Station P and B.C. Coastal Waters*
E.V.S. Consultants, N. Vancouver, B.C. ..... 954

*Identification and Enumeration of Marine Phytoplankton from British Columbia Coastal Waters*
E.V.S. Consultants, N. Vancouver, B.C. ..... 4,493

*Benthic Studies in Hecate Strait*
E.V.S. Consultants, N. Vancouver, B.C. ..... 20,000

*Study of the Commercial Potential of the Galatheid Crab* Munida quadrispina *in B.C. Crustacean Fishery*
Galatea Research, Brentwood Bay, B.C. ..... 37,425

*Sorting of Benthic Samples in Formalin*
M. Galbraith, Victoria, B.C. ..... 800

*Modifications to Tidal Model to Convert to a Tsunami Model*
G. Gatien, Sidney, B.C. ..... 3,720

*Support Services to Carry Out Multi-Laboratory Performance Checks*
D. Goode, Victoria, B.C. ..... 5,000

*Collection and Compilation of Oceanographic Data in the Campbell River and Fraser River Estuaries*
A. Hartley, Vancouver, B.C. ..... 6,080

*Continued Collection and Compilation of Oceanographic Data at Campbell River*
A. Hartley, Vancouver, B.C. ..... 3,999

*Modifications to Shallow Water Modelling Package Developed at IOS*
K. Holtham, North Saanich, B.C. ..... 600

*Preparation and Production of the Beaufort Sea Overview Report Entitled "Marine Fishes, Invertebrates and Marine Plants: The Search for Oil"*
Hoot Productions Ltd., Victoria, B.C. ..... 22,865

*Analysis of Data From Prototype Sonar System*
B. Huber, Victoria, B.C. ..... $ 2,400

*Preparation and Testing of Equipment for Gibraltar Strait Experiment*
B. Huber, Victoria, B.C. ..... 5,210

*Documentation and Data Analysis of Dec'84 Echometer Cruise*
D. Huston, Victoria, B.C. ..... 4,000

*Crane Dynamic Loading with Motion Compensation for At-sea Lifing Operations*
Hymarc Engineering Ltd., Ottawa, Ontario ..... 91,585

*A Study into the Dynamics of Small Scale Variability*
Interact R & D Corporation, Victoria, B.C. ..... 45,412

*Evaluation of a Statistical Theory of Tracer Transports*
Interact R & D Corporation, Victoria, B.C. ..... 7,902

*Development of Data Display Programmes*
Interact R & D Corporation, Victoria, B.C. ..... 6,030

*Evaluation of Hydrographic Launch Dynamics Data*
Interact R & D Corporation, Victoria, B.C. ..... 7,503

*Development of the Oceanographic Data Inventory System-Programme Updating and Adaption to Digital Equipment*
Interact R & D Corporation, Victoria, B.C. ..... 29,989

*Software Changes to ISAH*
Interact R & D Corporation, Victoria B.C. ..... 11,625

*Implementation of the 32 Bit Kernel, Utilities and Data Acquisition on the HAL Computer*
Interact R & D Corporation, Victoria, B.C. ..... 1,114

*Collection and Analysis of Samples from Moored and Free Drifting Sediment Traps*
ISK Environmental Research, Saanichton, B.C. .. 21,473

*Collection, Analysis and Storage Tests of Samples and Free-Drifting Sediment Traps*
ISK Environmental Research, Saanichton, B.C. .. 24,571

*Preparation of a Report on Sequential and Simple Sediment Traps*
ISK Environmental Research, Saanichton, B.C. .. 988

*Development of an Undersea Acoustic Technique to Determine Rainfall*
Jasco Research Ltd., North Saanich, B.C. ..... 8,900

*Study of the Effect of Current Speed on Freezing and Melting Sea Ice*
D. Knigge-Seiberg, Victoria, B.C. ..... 21,000

*Development of an Underwater Acoustic Imager*
Knudsen Engineering Ltd., Stittsville, Ontario $ 238,181

*Chemistry Literature Review on Carbon Dioxide Project*
V. Kumar, Victoria, B.C. ..... 3,000

*Improvements to the Thacker Method for Tidal Models*
Dr. Loomis, University of Hawaii ..... 1,500

*Develop Techniques for Measuring Rainfall at Sea*
Jeffrey A. Nystuen, Patricia Bay, B.C. ..... 47,834

*Develop and Test an Ambient Noise Sensor for Wind Speed Measurements*
Metocean Data Systems Ltd., Dartmouth, N.S. ..109,753

*Hydro-thermal Plume Modelling Study*
J.H. Middleton, Saanichton, B.C. ..... 6,000

*Continuation of Technical Improvements and Evaluation of FLI*
Moniteq Ltd., Concord, Ontario ..... 33,728

*Continuation of Technical Improvements and Evaluation of FLI*
Moniteq Ltd., Concord, Ontario ..... 35,207

*Develop Electronic Imaging Techniques Using FLI for Bathymetry and Bottom Type Detection*
Moniteq Ltd., Concord, Ontario .....149,039

*Aerial Photographic Survey and Mapping of North Coast of Vancouver Island*
McElhanney Group Ltd., Vancouver, B.C. ..... 19,306

*Development and Provision of Long Range Capabilities to Existing Argo and Hi-Fix Equipment*
McElhanney Group Ltd., Vancouver, B.C. .....244,929

*Preparation of Active Drifter for Offshore Tests*
Oceanetic Measurements Ltd., Victoria, B.C. .... 9,960

*Field Test of Offshore Active Drifter*
Oceanetic Measurements Ltd., Victoria, B.C. .... 6,104

*Analysis of Satellite Tracked Drifter Data for the B.C. Coast*
Odysseas Ocean Sciences Ltd., North Saanich, B.C. ..... 3,120

*Analysis of Satellite Tracked Drifter Data for the West Coast of the United States*
Odysseas Ocean Sciences Ltd., North Saanich, B.C. ..... 2,925

*Investigation of Hydro-Acoustical Estimate of the Under Ice Morphology in the Arctic Ocean*
Odysseas Ocean Sciences Ltd., North Saanich, B.C. ..... 4,485

*Survey of Acoustic Profiling of an Arctic Ice Keel, Phase II*
Offshore Survey and Positioning Services Ltd., North Vancouver, B.C. ..... $ 36,040

*Implementation of Tropical Ocean-Global Atmosphere (TOGA) Observing Systems*
Pacific Ocean Sciences Ltd., Burnaby, B.C. ..... 40,400

*Data Interception of Ships-of-Opportunity*
Pacific Ocean Sciences Ltd., Burnaby, B.C. ..... 1,320

*Observations of Tides in the N.W. Passage*
Pacific Ocean Sciences Ltd., Burnaby, B.C. ..... 24,948

*Study of Numerical Prediction of Wind Generated Waves in the Coastal Sea Between Queen Charlotte Islands and the Mainland Coast of British Columbia*
Pacific Ocean Sciences Ltd., Burnaby, B.C. ..... 15,000

*To Supply an Enhanced HAL System*
Quester Tangent Corp., Victoria, B.C. ..... 50,920

*To Supply 5 X 512K Byte Bubble Cartridges for ISAH*
Quester Tangent Corp., Victoria, B.C. ..... 29,375

*Preparation of a Report on Pacific Transportation of Heat and Salt Paths Planning Meeting*
S & B Research, Saanichton, B.C. ..... 1,440

*Evaluation of Impact of New Observing Systems on Severe Sea State Warnings for the B.C. Coast*
Seaconsult Marine Research Ltd., Vancouver, B.C. .....119,819

*Study to Develop a SAR Procedure for Hazardous Waters*
Seaconsult Marine Research Ltd., Vancouver, B.C. .....165,000

*Evaluation of Tsunami Levels Along the B.C. Coastline*
Seaconsult Marine Research Ltd., Vancouver, B.C. .....242,000

*Analysis of Summary Statistics from West Coast Ships-of-Opportunity*
Seakem Oceanography Ltd., Sidney, B.C. ..... 11,123

*Inventory of Chemical Oceanography Data for the Sverdrup River Basin*
Seakem Oceanography Ltd., Sidney, B.C. ..... 44,975

*Study of Partitioning of Cadmium and Lead Between False Creek Dredge Spoils and Seawater*
Seakem Oceanography Ltd., Sidney, B.C. .....102,469

*Interpretation of Hydrographic Data in the North West Passage*
Seakem Oceanography Ltd., Sidney, B.C. ..... $ 18,027

*Analysis of Marine Air Samples from Land Stations and Ocean Cruises*
Seakem Oceanography Ltd., Sidney, B.C. ..... 22,970

*Analysis of Dissolved Nutrients in Seawater and Artificial Sea Water*
Seakem Oceanography Ltd., Sidney, B.C. ..... 9,400

*Feasibility Study of the Development of a Deep Oceanic Drifter*
Seastar Instruments, Sidney, B.C. ..... 9,829

*Testing and Evaluation of a Novel Acoustic Release*
Seastar Instruments, Sidney, B.C. ..... 86,490

*Development of a Fibre Optic Dissolved Oxygen Sensor*
Seastar Instruments, Sidney, B.C. ..... 227,955

*Development of an Intelligent Serial Interface Board for a Miniranger III Positioning System*
Seastar Instruments, Sidney, B.C. ..... 7,987

*Develop and Test a Computer Model for Simulating the Doppler Spectrum of Acoustic Waves Backscattered from the Ocean Surface*
SH Scientific Computing Services, Vancouver, B.C. ..... 6,040

*Calibration, Installation and Testing of CTD/Rosette System on* CSS Parizeau
SH Scientific Computing Services, Vancouver, B.C. ..... 1,583

*Analysis of Hecate Strait Bio-oceanographic Data*
SH Scientific Computing Services, Vancouver, B.C. ..... 3,995

*Design and Develop Computerised Databases for Co-ordination and Management of Job Development Programs*
Soft-Tech Development Corp., Victoria, B.C. ..... 3,998

*Preparation of Geostrophic Current Mapping Programmes*
M.D. Speedie, Victoria, B.C. ..... 1,300

*Preparation of Turbulence Profiler FLY II for Field Use*
Sy-Tech Research Ltd., Sidney, B.C. ..... 5,190

*Data Acquisition System for* Pisces IV
Sy-Tech Research Ltd., Sidney, B.C. ..... 18,783

*Preparation of Planning Chart of the Beaufort Sea*
Terra Surveys, North Saanich, B.C. ..... 2,500

*Development of Correlation of Uni-polar Data Pulses*
Thalassic Data Ltd., Sidney, B.C. ..... $ 14,457

*Co-ordination of 3 Consecutive International Tsunami Meetings*
Tide and Tsunami Services Ltd., Saltspring Island, B.C. ..... 13,634

*Numerical Modelling Studies of the Strait of Georgia (Part VII)*
University of British Columbia, (Dr. Burling), Vancouver, B.C. ..... 26,000

*Continuation of Study of Comparison of Freon Techniques in Seawater*
University of Victoria, Victoria, B.C. ..... 2,000

*Development of a Geo-thermal Model of Freon Transfer from the Atmosphere into the Ocean*
University of Victoria, Victoria, B.C. ..... 10,354

*Provision of Backscatter and Ambient Sound Data in the Atlantic Ocean*
S. Vagle, Brentwood Bay, B.C. ..... 1,990

*A Laboratory Investigation of Salinity Driven Slope Convection*
B. VanHardenberg, Sidney, B.C. ..... 8,500

*Preliminary Testing of Small Scale Wave Tank*
B. VanHardenberg, Sidney, B.C. ..... 1,350

*Development of a Launch Engine Information System*
Vargas Consulting, Victoria, B.C. ..... 11,585

*Time Series Analysis of Scintillation Data*
J. Verrall, Victoria, B.C. ..... 1,080

*Modifications to BERT 101 Range and Bearing Acquisition System*
Walker Industrial Computing Ltd., North Saanich, B.C. ..... 8,35[illegible]

*Identify and Enumerate Phytoplankton Collection by the Ship-of-Opportunity Project*
R. Watters, Guildford, Surrey, England ..... 2,000

*Literature Review on Carbon Cycling Models*
Western Ecological Services Ltd., Victoria, B.C. .. 10,135

*Development of a Biological Pump Model of $CO_2$ Removal from Surface Sub-Arctic Waters into Deep-Water Storage Via Detritus Fluxes of Fecal Pellets and Calareous Shells*
Western Ecological Services Ltd., Victoria, B.C. .. 4,280

*Prepare Reports on $CO_2$ Data from Ocean Station Papa and Ships-of-Opportunity Programmes*
Western Ecological Services Ltd., Victoria, B.C. .. 10,330

*Modelling and Analysis of Data from West Coast of Queen Charlotte Islands, Dixon Entrance and Hecate Strait*
R. Wilson, North Saanich, B.C. ..... $ 18,921

*Sorting of Benthic Samples Fixed in Formalin*
R. Woods, Sidney, B.C. ..... 750

*Organize West Coast Ocean Dumping Workshop 1985 and Prepare Workshop Proceedings for Publication*
S.M. Woods, Sidney, B.C. ..... 4,010

*Study of the Variability of the Total Ocean to Atmosphere Heat Exchange*
Yong Ping Zhao, Sidney, B.C. ..... 12,000

## B. Department of Energy, Mines and Resources

*Preparation of Illustrations, Pacific Geoscience Centre*
L. Bedard, Victoria, B.C. ..... $ 25,000.00

*Picking and Sorting of Microfossils*
Cameron Biostratigraphic Services, Victoria, B.C. ..... 6,000.00

*Preparation of a Manuscript on the Early and Middle Jurassic Radiolarian Biostratigraphy of the Queen Charlotte Islands*
E.S. Carter, consultant, Vancouver, B.C. ..... 4,000.00

*Preparation of a Report on Biostratigraphy on the Basis of Fossil Radiolaria from Selected Mesozoic Rocks of the Insular Belt*
E.S. Carter, consultant, Vancouver, B.C. ..... 6,000.00

*Operation and Maintenance of a Regional Seismic Station in Prince Rupert and Telemetered Stations in the Queen Charlotte Islands*
B. Chandra & Associates Ltd., Vancouver, B.C. .. 8,025.00

*Investigation of Geohazards to Development on the Continental Shelf off Western Canada*
K. Conway, Victoria, B.C. ..... 7,350.00

*The Study of Upper Crustal Structure Below Hecate Strait from Airgun/Ocean Bottom Seismograph Data*
Dr. R.M. Clowes, Dept. Geophys. & Astron., U.B.C. ..... 14,833.00

*Acquisition of Crustal Refraction Data on Juan de Fuca Ridge*
Dr. R.M. Clowes, Dept. Geophys & Astron., U.B.C. ..... $ 23,408.00

*Seismographic Data Collected at Selected Sites on the West Coast of British Columbia*
Dr. R.M. Ellis, Dept. Geophys. & Astron., U.B.C. ..... 10,975.00

*Earthquake Studies in the Beaufort Sea*
Dr. G.D. Garland, U. of Toronto. ..... 14,710.00

*Acquisition, Compilation and Analysis of Marine Geological and Geophysical Data from the Continental Shelf and Adjacent Offshore Regions of Western Canada*
Geomartec Services, Brentwood Bay, B.C. .... 18,375.00

*Offshore Multichannel Seismic Profiling*
Geophoto Ltd., Calgary, Alta. ..... 630,000.00

*SeaMARC II Survey of the Northern Juan de Fuca Ridge System and Vancouver Island Continental Slope*
Hawaii Institute of Geophysics, Honolulu, Hawaii. ..... 437,533.00 (U.S.)

*Radiocarbon Dating of Shell Samples*
Isotrace Laboratory (Univ. of Toronto) ..... 5,184.00

*Marine Survey of the Surficial Geology and Morphology of Northwestern Graham Island*
Offshore Survey and Positioning Services Ltd., North Vancouver, B.C. ..... 54,600.00

*Supply of Electronics for Telemetering Heat Probe*
Polar Tech Ltd., Sidney, B.C. ..... 75,684.00

*Compilation of a Digital Terrain File in Selected Areas of the Western Cordillera*
SIAL, Compagnie Internationale de Géophysique Inc. Dorval, Quebec. ..... 102,037.00

*Precise Gravity Survey of Selected Sites on Vancouver Island*
SIAL, Compagnie Internationale Géophysique Inc. Dorval, Quebec. ..... 27,772.00

*A Comparison of LANDSAT 5 and Airborne Multispectral System for Coastal Remote Sensing*
Simon Fraser University (Geography Dept.). . 6,500.00

*Computer Based Mapping of Coastal Geomorphology and Lidimentology*
E. Strong, Calgary, Alta. ..... 6,000.00

*Lithoprobe Profiles One and Three 1985 Field Component-Geological Mapping*
A. Sutherland Brown, Victoria, B.C. ..... $ 55,000.00

*Grain Size Analysis of Sediment Samples from the West Coast of Canada*
Thurber Consultants Ltd., Victoria, B.C. .... $ 27,126.00

Awards:

Canadian Society of Petroleum Geologists Medal of Merit, 1983; presented in February, 1985 to Dr. C.J. Yorath.

# APPENDIX II

## Publications, 1985

### (1) Canadian Data Report of Hydrography and Ocean Sciences

BIRCH, J.R., E.C. LUSCOMBE, D.B. FISSEL and L.F. GIOVANDO. *West Coast Data Inventory and Appraisal. Dixon Entrance, Hecate Strait, Queen Charlotte Sound and Adjoining B.C. Coastal Waters: Physical Oceanography–Temperature, Salinity, Currents, Water Levels and Waves, 1903 through 1984.* No. 37, Vol. 1; Part 1, 310 pp, Part 2, 271 pp.

BUCKINGHAM, W.R., R.A. LAKE and H. MELLING. *Temperature and Salinity Measurements in the Northwest Passage, in March-April, 1982.* Vol. 1, No. 39, 371 pp.

DENMAN, K., R. FORBES, D. MACKAS, S. HILL and H. SEFTON. *Ocean Ecology Data Report: British Columbia Coastal Waters, 29 June-10 July, 1983.* No. 36, 77 pp.

GIOVANDO, L.F. *Observations of Seawater Temperature and Salinity at British Columbia Shore Stations, 1983.* No. 30, 112 pp.

GIOVANDO, L.F. *Observations of Seawater Temperature and Salinity at British Columbia Shore Stations, 1984.* No. 41, 105 pp.

SACKMAN, T. and B.D. SMILEY. *Arctic Industrial Activities Compilation. Sverdrup Basin: Hydrocarbon Exploration 1974 to 1984.* No. 32, Vol. 2, 194 pp.

TABATA, S. and J.L. PEART. *Statistics of Oceanographic Data Based on Hydrographic/STD Casts Made at Ocean Station P during August 1956 through June 1981.* No. 31, 140 pp.

TAYLOR, D.A., M.G. REED, B.D. SMILEY and G.S. FLOYD. *Arctic Industrial Activities Compilation. Beaufort Sea: Marine Dredging Activities 1959 to 1982.* No. 32, Vol. 1, 205 pp.

THOMSON, R.E., W.R. CRAWFORD, H.J. FREELAND and W.S. HUGGETT. *Low-Pass Filtered Current Meter Records for the West Coast of Vancouver Island: Coastal Oceanic Dynamics Experiment, 1979-1981.* No. 40, 108 pp.

## (2) Canadian Technical Report of Hydrography and Ocean Sciences

RAMSDEN, D., D. WHITFIELD and G. HOLLOWAY. *Spectral Transform Simulations of Turbulent Flows, with Geophysical Applications.* No. 57, 59 pp.

VERMEER, K. *A Five-Year Summary (1978-1982) of the Nestling Diet of Cassin's Auklets in British Columbia.* No. 56, 18 pp.

VERMEER, K. and L. RANKIN. *Pelagic Seabird Population in Dixon Entrance.* No. 65, 25 pp.

## (3) Canadian Contractor Report of Hydrography and Ocean Sciences

ANDERSON, E.P. *Effects of Suspended Tailing from the AMAX/Kitsault Mine on the Predation Rates of the Marine Zooplankters* Euchaeta elongata *and* Euphausia pacifica. No. 21, 26 pp.

WOODS, S.M., (ed.). *Report on Ocean Dumping R&D Pacific Region. Department of Fisheries and Oceans 1983-84.* No. 20, 62 pp.

# (A) Department of Fisheries and Oceans

ARMI, L. and D.M. FARMER. 1985. The internal hydraulics of Gibralter Strait and associated sills and narrows. *Oceanologica Acta,* **8:** 37-46.

BENNETT, A.F. and K.L. DENMAN. 1985. Phytoplankton patchiness: inferences from particle statistics. *J. Mar. Res.,* **43:** 307-335.

BENNETT, A.F. 1985. Absolute velocity and the thermodynamics of seawater. *Ocean Modelling,* Oxford University/U.S. Office of Naval Research, **62:** 1-3.

BORSTAD, G.A., J.F.R. GOWER, H.R. EDEL and A.B. HOLLINGER. 1985. Analysis of test and flight data from the Fluorescence Line Imager. *Can. Spec. Publ. of Fisheries and Aquatic Sciences*, No. 83, 38 pp.

BRINKHURST, R.O. 1985. A further contribution to the taxonomy of the genus *Tubificoides* Lastockin (Oligochaeta: Tubificidae). *Can. J. Zool.*, **63:** 400-410.

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EL-SABH, M.I., B. TESSIER and T.S. MURTY. 1985. Fractal dimension and length of an irregular coastline. *Science of Tsunami Hazards*, **3(1):** 41-44.

FARMER, D.M. and R.A. DENTON. 1985. Hydraulic control of flow over the sill in Observatory Inlet. *J. Geophys. Res.*, **90(C5):** 9051-9068.

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# (C) Department of Energy, Mines and Resources

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# APPENDIX III

## Permanent Staff 1985
## Institute of Ocean Sciences

## A. Department of Fisheries and Oceans

### Director-General

Mann, C.R.; B.Sc., M.Sc. (N.Z.), Ph.D. (Brit. Col.), D. Eng. (N.S. Tech), F.R.S.C.
* Van Dusen, T.S.
** McDonald, L.J.

### Management Services Division

*Chief of Division:*
Todd, N.A.; B.Sc. (Glasgow), M.A. (Carleton)

Anderson, M.
Coldwell, J.H.
Cooper, B.J.
Curtis, J.N.
Doxey, K.
Drysdale, A.E.
* Firth, C.
Gent, C.E.
Grills, C.J.
Hanmer, M.P.
Hope, T.
Keding, L.M.
Kroeger, K.
Kusch, R.R.
Lafortune, A.J.; B.A. (Manitoba)
Lapp, B.I.; B.A. (Victoria)
Lohrmann, B.A.; B.Sc. M.Sc. (Guelph)
MacMillan, B.C.
Oakfield, C.L.
Sabourin, J.T.
Smith, K.R.
Thomson, L.S.C.; B.A. (Sask.), B.L.S. (Brit. Col.)
Tillie, D.G.
Van Eyk, W.J.
Watts, F.

**Commissionaires:**

Sgt. Price, D.W.
Sgt. Hull, N.S.B.
Comm. Alexander, F.
Comm. Ashton, B.
Comm. Hill, E.
Comm. Moe, L.
Comm. Moffat, H.
Comm. Morris, R.
* Comm. Trerice, L.
Comm. Wilson, W.

* Left in 1985
** Joined in 1985

## Personnel

*Regional Personnel Manager:*
Hamilton, K.R.; B.A. (Brit. Col.)

Groves, L.D.; Dip. (Victoria)
Knapp, B.M.
Linguanti, S.C.
Olauson, E.J.
Renstrom, M.
Trentelmann, E.

## Hydrography

*Director of Hydrography:*
* Bolton, M.; C.L.S.
** O'Connor, A.D.; C.L.S.

Ages, A.B.; B.A.Sc., M.A.Sc. (Brit. Col.), P. Eng.
Bell, R.D.
Canning, B.
Chan, L.M.
Chapeskie, R.E.
Coldham, F.A.
Collins, T.
Crawford, W.R.; B.Sc., M.A.Sc. (Waterloo), Ph.D. (Brit. Col.)
Crowley, J.V.; C.L.S.
Crowther, W.S.; CC (Ont. Inst. of Chartered Cartographers)
Curran, T.A.; B.A.Sc. (EE), M.Sc. (Brit. Col.), P. Eng.
Czotter, K.L.; Dip. BCIT
Dobson, D.G.
Dorosh, L.W.; Dip. BCIT
Douglas, A.; B.Sc. (Victoria)
Earl, E.L.P.
Eaton, G.H.; Dip. BCIT, B.Sc. (UNB), C.L.S.
Farmer, P.M.
Fisher, D.L.
Galloway, J.L.; B.A.Sc. (EE), M.A.Sc. (EE) (Brit. Col.), P. Eng.
Gould, J.M.
** Gresham, G.E.
Halcro, K., Dip. BCIT
Hare, R.; Dip. BCIT
Hermiston, F.V.
Hinds, E.W.; Dip. BCIT
Hinds, S.D.
Hohl, M.
Hollinger, C.; Dip. BCIT
Holman, K.R.
Huggett, W.S.; Master (FG), C.L.S.
Jackson, D.M.; B.Sc. (Victoria)
Jackson, T.L.
Jennings, M.J.
Jodrell, D.A.
Johnson, B.A.; Dip. BCIT
Kenny, B.
** Kerr, B.; Dip. Seneca, B.A. (York)
Kidson, G.G.
Korhonen, R.K.
Larkin, J.B.; B.Sc. (PEI)
Lee, K.S.
Lewis, B.V.; Dip. BCIT
* Lloyd, I.M.; Dip. BCIT
Loschiavo, R.; Dip. BCIT
Lusk, B.C.; Master (350T), C.L.S.
Lyngberg, K.; Dip. BCIT
Lyon, A.G.
MacPhail, G.
* McGregor, B.G.; Dip. BCIT
Milner, P.R.; Dip. BCIT
Moody, A.E.
*** Mortimer, A.R.; Master (FG), B.Sc. (Victoria), C.L.S.
Muse, R.A.; Trade Cert. CAF
Nowak, C.; Dip. BCIT
** Parkhouse, P.J.
Parks, J.R.; B.A.Sc. (EE) (Brit. Col.)
Pfluger, H.A.
Philp, A.R.
Pickell, L.M.
Pierce, R.A.
Popejoy, R.D.
** Prince, D.W.; B.A. (Victoria)
Rapatz, W.J.; B.Sc. (Victoria), C.L.S.
Raymond, A.R.; Dip. (Algonquin College)
Redman, D.
Richardson, G.E.; C.L.S.
* Roberts, J.W.; Master (FG), Cdr. RCN (Ret'd)
Ross, A.D.; CC (Ont. Inst. of Chartered Cartographers)

Sadlish, J.P.
Sandilands, R.W.; Lt. (H) RN (Ret'd), C.L.S. FRGS
Sargent, E.D.; Dip. BCIT
** Schlagintweit, G.E.; Dip. BCIT
Schofield, A.J.
Schofield, B.D.; B.Sc. (Victoria)
Smedley, A.J.; L. Cdr. RCN (Ret'd)
Smith, A.; Master (FG)
Smith, G.R.; B.A.Sc. (ME) (Brit. Col.), P. Eng.
Steeples, J., Cert. Mech. Eng. (Edinburgh)
Stephenson, F.E.; B.Sc. (Victoria)
Taylor, W.R.; Dip. BCIT
Thompson, L.G.
Thomson, A.D.; Dip. BCIT
Tuck, B.D.; B.Sc. (Victoria)
Vear, M.
Ward, M.M.; Dip. BCIT, B.A. (Lakehead)
Watt, B.M.
** Wells, I.C.; B.Sc. (Victoria)
Whincup, G.
Woods, M.V.; Dip. BCIT, B.Sc. (Calgary)
Woodward, M.J.; B.Sc. (Victoria), M.Sc. (Toronto)
Woolley, R.; Dip. BCIT
Yee, J.

* Left in 1985
** Joined in 1985
*** Seconded to Quebec Region

## Ship Division

*Regional Marine Superintendent:*
Parkinson, R.W.; Engineer 1st Class, Member; Institute of Marine Engineers

Fitch, L.A.H.; Master, H.T.; Assist. Marine Superintendent
Doyle, D.A.; Secretary
Craton, M.; Administrative Clerk

CSS JOHN P. TULLY

Newton, B.L.; Master F.G., Master
Coombes, A.S.; ON.1, Chief Officer
Campbell, J.D.; 2nd Officer
Purdie, J.; 3rd Officer
Pereira, P.B.; Eng. 1st Class Combined, Chief Engineer
Stanway, J.D.; Eng. 2nd Class Motor, 2nd Engineer
Murphy, P.J.
Kirkby, D.
Garneau, G.C.
Law, S.
Keene, A.R.
Graham, D.B.
Aucoin, A.E.
Clark, L.E.
Boughton, D.G.E.
Napier, J.W.
Prunkl, W.J.
Manifold, G.C.
Heesterman, D.N.
McRae, A.R.
Smart, T.R.
Brown, D.G.
Contois, W.M.

CSS PARIZEAU

Chamberlain, A.G.; Master F.G., Master
Gimbel, K.; W.K.M., 3rd Officer
Winterburn, G.; Eng. 1st Class Motor Chief Engineer
Tran, K.H.; Eng. 2nd Class Motor, Senior 2nd Engineer
Dowhy, J.; Eng., 3rd Engineer
Carter, R.A.
Purdie, D.; Eng. 4th Class Motor, 4th Engineer
Palmer, S.; Supply Officer
Begoray, N.
Weston, A.
Cooke, B.E.
Waistell, G.A.
Waterfall, J.P.
Camiot, M.
Smith, J.R.
Springett, B.R.
Brown, J.D.
Fidler, M.J.
Keene, A.
Fowke, K.
Knoblauch, D.
Laforest, B.G.
Begin, P.
Kirk, M.J.
Greene, J.S.

CSS VECTOR

MacKenzie, R.W.; Master H.T., Master
Wheeler, M.G.; Master H.T., 1st Officer
Pearson, R.; Eng. 3rd Class Motor, Chief Engineer
Braithwaite, P.M.
Robie, D.J.
Anderson, D.D.
Simpson, F.W.
Lavigne, R.
McKechnie, D.G.
Burns, R.G.
White, R.M.
Scoones, A.E.
Fisher, P.R.
Cadorin, G.D.

CSS RICHARDSON

LeGarff, J.; W.K.M., Master
Jamieson, T.A.
Scott, R.C.

PISCES IV

Chambers, F.J.; Chief Pilot
Taylor, R.H.
Witcombe, A.E.
Oszust, J.S.
Shepherd, K.
Holland, R.R.

SHORE PARTY AND RELIEF POOL

Frost, P.A.
Elliott, H.G.; O.N.II
Beebe, E.; Eng. 4th Class Motor
Thompson, D.
Moore, A.; Eng. 4th Class Motor
Allison, G.R.
Lovelace, R.S.
Sanderson, R.L.
Simmons, B.R.
Williams, L.

DECK MACHINERY

Bradbury, J.D.

INSTITUTE WORKSHOPS

Smith, F.V.; Supervisor
McNeill, J.; Foreman
Badminton, E.C.
Barlow, L.
Bell, W.
Ennis, J.F.
Green, G.E.
Gurney, J.P.
Nelson, B.J.
Noren, R.J.S.
Smith, G.J.
Thompson, B.R.
Williams, P.D.

## Ocean Information

*Chief of Division:*
** Wilson, R.C.H.; B.Sc. (Simon Fraser), M.S. (Western Washington)

Giovando, L.F.; B.A., M.A., Ph.D. (Brit. Col.)
Glover, K.T., B.A. (UNB)
*** Pitcher, J.A.
Smiley, B.C.; B.Sc., M.Sc. (Alberta)

** Joined in 1985
*** Educational Leave

## Ocean Chemistry Division

*Chief of Division:*
Wong, C.S.; B.Sc., M.Sc. (Hong Kong), Ph.D. (Scripps), Dip. Mar. Sc. (UNESCO), F.R.S. Chem. (U.K.), F.C.I.C.

Bellegay, R.D.; Dip. NAIT, Assoc. Deg. in Oceanography (Shoreline Community College, Seattle)

Cretney, W.J.; B.Sc., Ph.D. (Brit. Col.)
Johnson, W.K.; Dip. BCIT
Macdonald, D.M.; B.A.Sc. (Brit. Col.), Dip. (Camosun College)
Macdonald, R.W.; B.Sc., Ph.D. (Dalhousie)
McLaughlin, F.A.; B.Sc. (Victoria)
O'Brien, M.C.; B.Sc. (Alberta)
Paton, D.W.; B.Sc. (Brit. Col.)
Poulin, J.G.
Smith, G.L.; Dip. NAIT
Soutar, T.J.; Dip. BCIT
Thompson, J.A.J.; B.Sc. (McMaster), Ph.D. (Alberta), F.C.I.C.
Whitney, F.A.; B.Sc. (Brit. Col.)

## Ocean Physics Division

*Chief of Division:*
Garrett, J.F.; B.A. (Harvard), Ph.D. (Brit. Col.)

Bell, W.H.; B.A.Sc. (Brit. Col.), M.Sc. (Hawaii), P. Eng.
Bennett, A.F.; B.Sc. (U. of Western Australia), M.S., Ph.D. (Harvard)
Bigham, R.W.
Budgell, W.P.; B.A.Sc. (Waterloo), M.Eng. (McMaster), Ph.D. (Waterloo)
Chase, G.W.; Dip. BCIT
Cooke, R.A.; Dip. RCC
Crean, P.B.; B.Sc. (Dublin), M.A.Sc. (Toronto), Ph.D. (Liverpool)
de Jong, C.
Delacretaz, A.
Farmer, D.M.; B.Comm., M.Sc. (McGill), Ph.D. (Brit. Col.)
Francis, D.B.; B.Sc. (Victoria)
Freeland, H.J.; B.A. (Essex), Ph.D. (Dalhousie)
Gargett, A.E.; B.Sc. (Manitoba), Ph.D. (Brit. Col.)
Gower, J.F.R.; B.A., M.A., Ph.D. (Cantab)
Henry, R.F.; B.Sc. (Edinburgh), Ph.D. (Cantab)
Holloway, G.; B.A., M.S., Ph.D. (California)
Johnston, P.
Kamitakahara, G.R.; B.Sc. (Toronto)
Koppel, A.W.
Kimber, P.M.
Lake, R.A.; B.Sc. (Brit. Col.), M.Sc. (Washington)
Lee, A.Y.P.; B.Sc. (Victoria)
Lewis, E.L.; B.Sc., M.Sc., Ph.D. (London)
Love, J.
Mathias, A.L.
* Meikle, J.H.
Melling, H.; B.Sc., M.Sc., Ph.D. (Toronto)
Minkley, B.G.; Dip. BCIT
Miyake, M.; B.S. (EE) (Drexel), M.S., Ph.D. (Washington)
Moonie, J.A.
Moorhouse, S.W.
Murty, T.S.; B.Sc., M.Sc. (Andhra), M.S., Ph.D. (Chicago)
Perkin, R.G.; B.A.Sc., M.Sc. (Brit. Col.)
Quay, L.
Richards, D.L.
Spearing, L.A.F.; B.Sc. (Brit. Col.)
Stickland, J.A.
Stucchi, D.J.; B.A.Sc. (York), M.Sc. (Dalhousie)
Sudar, R.B.; B.A.Sc. (Toronto)
Tabata, S.; B.A., M.A. (Brit. Col.), D.Sc. (Tokyo)
Teichrob, R.C.; Dip. BCIT
Thomson, R.E.; B.Sc., Ph.D. (Brit. Col.)
Topham, D.R.; D.L.C., D.C.A.E., Ph.D. (Loughborough)
Wallace, J.S.
Wu, L.S.C.; B.Sc. (Brit. Col.)

* Left in 1985

## Computing Services

*Head:*
**** Teng, K.; B.A.Sc., M.A. (Brit. Col.)

*Acting Head:*
Johns, R.E.; B.Sc. (Victoria), M.Sc. (Brit. Col.)

Douglas, A.N.; B.Sc. (Victoria)
Foreman, M.G.; B.Sc. (Queen's), M.Sc. (Victoria)
Green, J.W.; B.Sc. (Victoria)
Lee, D.K.; B.S. (Chosun-Korea), M.S. (Oregon)
Lee, K.S.; B.Sc. (Victoria)
Linguanti, J.; B.Sc. (Victoria)
Ma, A.C.; B.Sc. (Victoria)
*** Oraas, S.R.; B.A.Sc., M.A.Sc. (Brit. Col.)
Page, J.S.; B.Sc. (Brit. Col.)
Smith, L.J.; B.Sc. (Simon Fraser)
Woollard, A.L.; B.Sc. (Victoria)

*** Interchange Program
**** Personal leave

## Ocean Ecology Division

*Chief of Division:*
Brinkhurst, R.O.; B.Sc., Ph.D., D.Sc. (London)

** Brown, R.M.; B.Sc. (Brit. Col.)
Denman, K.L.; B.Sc. (Calgary), Ph.D. (Brit. Col.)
Forbes, J.R.; B.Sc. (Carleton), M.Sc. (Alberta)
Mackas, D.L.; B.S., M.S. (Washington), Ph.D. (Dalhousie)
Moore, D.F.; B.Sc. (McMaster)
Stone, M.

** Joined in 1985

## Post Doctoral Fellows

Altman, D.B.; B.Sc. (Mech. Eng.) (Cornell), M.Sc. (California), M.B.A. (Colorado), Ph.D. (California)
Dumais, J.F.; B.Sc. (Quebec), M.Sc. (Alberta), Ph.D. (Alberta)
McIntosh, P.C.; B.Sc. (Monash), Ph.D. (Monash)
* Nemec, A.F.; B.Sc. (Victoria), M.Sc. (Victoria), Ph.D. (Washington)
Nurse, C.R.; B.A. (Oxford), M.A. (Oxford), Ph.D. (Brit. Col.)
Simard, Y.S.; B.Sc. (Laval), Ph.D. (Laval)

* Left in 1985

# B. Department of Environment

## Atmospheric Environment Service

McBean, G.A.; B.Sc. (Brit. Col.), M.Sc. (McGill), Ph.D. (Brit. Col.)

## Canadian Wildlife Service

Vermeer, K.; M.Sc. (Brit. Col.), Ph.D. (Alberta)

# C. Department of Energy, Mines and Resources

## Pacific Geoscience Centre

*Director:*

Hyndman, R.D.; B.A.Sc., M.A.Sc. (Brit. Col.), Ph.D. (A.N.U.)

*Head, Marine Geology (G.S.C.):*

Currie, R.G.; B.Sc., M.Sc. (Brit. Col.)

*Chief Scientist, Pacific Geophysics Division (E.P.B.):*

Law, L.K.; B.A.Sc. (Toronto), M.Sc. (Western Ontario), Ph.D. (Cantab)

*Special Projects Officer (E.P.B.):*

Boyd, J.B.

## Administrative Group

McCormick, J.K., Head; B.A., M.A.I. (McGill)
** Brown, M.
Chisholm, D.M.
* McDonald, L.J.
** Jenner, E.A.
McLean, A.
Meeres, M.
Price, W.

* Left in 1985
** Joined in 1985

## Geomagnetic Section

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Auld, D.R.; B.A.Sc. (Brit. Col.)
DeLaurier, J.M.; B.Sc. (Queen's)
Irving, E.; M.A., Sc.D. (Cantab), D.Sc. (Hon., Carleton), F.R.S.C., F.R.S.
Wynne, P.J., B.Sc. (Queen's), M.Sc. (Memorial)

## Gravity, Geothermics and Geodynamics Section

Sweeney, J.F. Head; B.A., M.A., Ph.D. (S.U.N.Y., Buffalo)
* Riddihough, R.P., Head; B.Sc. (King's College, London), D.I.C., M.Sc. (Imperial College, London), Ph.D. (U. of London)
Bentkowski, W.H.; B.Sc. (Western Ontario)
Dragert, H.; B.Sc. (Toronto), M.Sc., Ph.D. (Brit. Col.)
Lewis, T.J.; B.A.Sc., M.Sc. (Brit. Col.), Ph.D. (Western Ontario)
Seemann, D.; B.Sc. (Brit. Col.)

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Bornhold, B.D.; B.Sc. (Waterloo), M.A. (Duke), Ph.D. (M.I.T., Wood's Hole)
Cameron, B.E.B.; B.Sc., M.Sc. (Alberta), P.Geol.
Hamilton, T.; B.Sc. (Case Western Reserve), A.M. (Indiana), Ph.D. (Alberta)
* Luternauer, J.L.; B.A. (Colby), M.A. (Duke), Ph.D. (Brit. Col.)
* McLaren, P.; B.Sc., M.Sc. (Calgary), Ph.D. (South Carolina)
Yorath, C.J.; B.Sc. (Brit. Col.), M.Sc. (Alberta), Ph.D. (Queen's)

## Pacific Geophysics Division Seismology Section

Weichert, D.H., Head; B.A.Sc., M.Sc.,Ph.D. (Brit. Col.)
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Gregory, M.J.
Horner, R.B.; B.Sc. (Manitoba)
Rogers, G.C.; B.Sc. (Brit. Col.), M.Sc. (Hawaii), Ph.D. (Brit. Col.)
Sawyer, B.; B.F.A. (Victoria)

## Technical Support Groups Geological Survey of Canada

Forbes, T.; B.Sc. (Simon Fraser)
Frydecky, I.I.; B.A.Sc., M.A.Sc. (Brit. Col.), P. Eng.
Hill, W.A.M.; Dip. (BCIT)
Horel, G.C.; B.Sc. (Royal Roads)
Jewsbury, G.C.; B.Sc. (Victoria)
Johns, M.; B.Sc. (Brit. Col.)
Mcdonald, R.D.; B.A.Sc. M.A.Sc. (Brit. Col.)

## Earth Physics Branch

Bone, M.N., Head; B.A.Sc. (Toronto)
Baldwin, R.E.; B.Sc. (Wyoming), M.Sc. (Alberta)
* Bennetts, H.J.
Bowker, D.
Whitford, H.A.
Wilde, M.H.J.

## Post Doctoral Fellows

Brandon, M.; B.Sc. (U.C., Santa Cruz), M.Sc., Ph.D. (Washington)
** Globerman, B.R.; B.Sc. (Washington), M.Sc. (Western Washington), Ph.D. (U.C., Santa Cruz)
Massey, N.; B.Sc. (Leeds), Ph.D. (McMaster)
Nobes, D.; B.Sc., M.Sc. Ph.D. (Toronto)
* Villinger, H.; Diplom. Ph.D. (T.U. Berlin)

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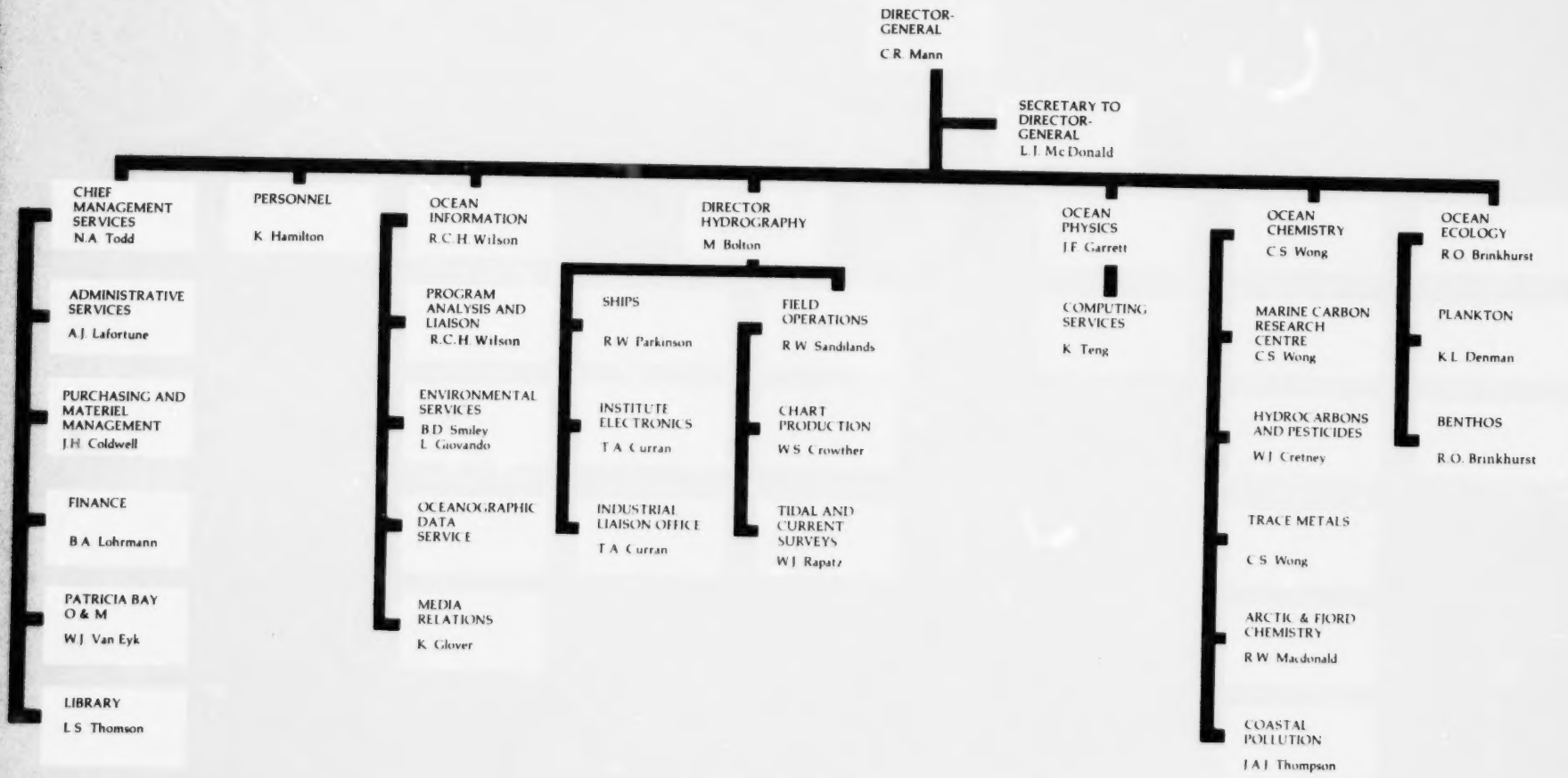
## Visitors

Barrie, V.; Memorial University
Brandon, L.; COGLA
Keen, M.J.; Atlantic Geoscience Centre
Smith, W.; D.S.I.R.; New Zealand
Wahlstrom, R.; University of Uppsala, Sweden

# Organization Chart

## Department of Fisheries and Oceans